

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
9 October 2003 (09.10.2003)

PCT

(10) International Publication Number
WO 03/083638 A2

(51) International Patent Classification⁷: G06F 3/06

(21) International Application Number: PCT/US03/09112

(22) International Filing Date: 25 March 2003 (25.03.2003)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
10/112,598 28 March 2002 (28.03.2002) US
10/109,583 28 March 2002 (28.03.2002) US

(71) Applicant: EMC CORPORATION [US/US]; 35 Parkwood Drive, Hopkinton, MA 01748 (US).

(72) Inventors: THIBAUT, Robert, A.; 17 Edmund Brigham Way, Westboro, MA 01581 (US). CASTEL, Daniel; 150 Beacon Street, Boston, MA 02116 (US). GALLAGHER, Brian; Two Old Harry Road, Southboro, MA 01772 (US). WILSON, Paul, C.; 105 West Hill Road, Mendon, MA 01756 (US). WALTON, John, K.; 22 King Philip Path, Mendon, MA 01756 (US). MACLELLAN, Christopher, S.; 27 Mozart Drive, Walpole, MA 02081 (US).

(74) Agents: SHARKANSKY, Richard, M. et al.; Daly, Crowley & Mofford, LLP, 275 Turnpike Street, Suite 101, Canton, MA 02021 (US).

(81) Designated State (national): JP.

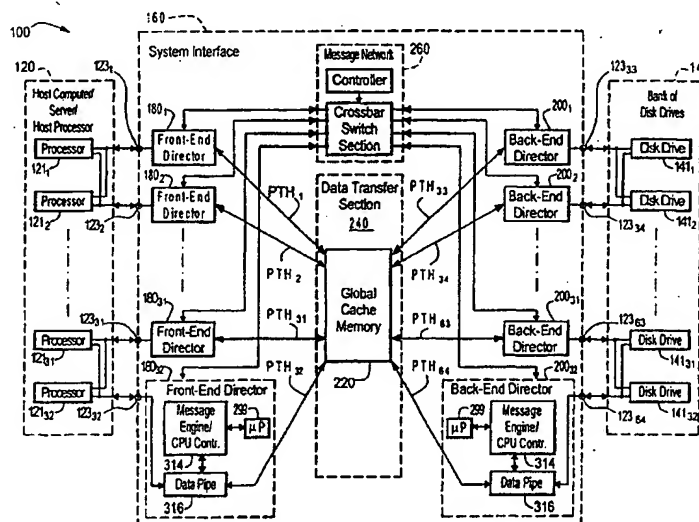
(84) Designated States (regional): European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PT, RO, SE, SI, SK, TR).

Declarations under Rule 4.17:

- as to the identity of the inventor (Rule 4.17(i)) for the following designations JP, European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PT, RO, SE, SI, SK, TR)
- as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii)) for the following designations JP, European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PT, RO, SE, SI, SK, TR)
- as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii)) for all designations
- as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii)) for all designations

[Continued on next page]

(54) Title: DATA STORAGE SYSTEM



(57) Abstract: A data storage system for transferring data between a host computer/server and a bank of disk drives. The system includes a backplane having slots adapted to have plugged therein a plurality of printed circuit board. The printed circuit boards include: a plurality of first director boards; a plurality of second printed circuit boards; a plurality of memory printed circuit boards; a plurality of dummy first director boards having first jumpers; a plurality of dummy second director boards having second jumpers; a plurality of dummy memory boards having third jumpers. Wiring of the backplane effects a connection among the first, second and third jumpers to interconnect a first plurality of director to a host computer/server, the plurality of second plurality of directors to a bank of disk drives and a global memory to the first plurality of directors and to the second plurality of director.

WO 03/083638 A2

BEST AVAILABLE COPY



Published:

— without international search report and to be republished
upon receipt of that report

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

DATA STORAGE SYSTEM

TECHNICAL FIELD

This invention relates generally to data storage systems, and more particularly to data storage systems having redundancy arrangements to protect against total system failure in the event of a failure in a component or subassembly of the storage system.

BACKGROUND

As is known in the art, large host computers and servers (collectively referred to herein as "host computer/servers") require large capacity data storage systems. These large computer/servers generally includes data processors, which perform many operations on data introduced to the host computer/server through peripherals including the data storage system. The results of these operations are output to peripherals, including the storage system.

One type of data storage system is a magnetic disk storage system. Here a bank of disk drives and the host computer/server are coupled together through an interface. The interface includes "front end" or host computer/server controllers (or directors) and "back-end" or disk controllers (or directors). The interface operates the controllers (or directors) in such a way that they are transparent to the host computer/server. That is, data is stored in, and retrieved from, the bank of disk drives in such a way that the host computer/server merely thinks it is operating with its own local disk drive. One such system is described in U.S. Patent 5,206,939, entitled "System and Method for Disk Mapping and Data Retrieval", inventors Moshe Yanai, Natan Vishlitzky, Bruno Alterescu and Daniel Castel, issued April 27, 1993, and assigned to the same assignee as the present invention.

As described in such U.S. Patent, the interface may also include, in addition to the host computer/server controllers (or directors) and disk controllers (or directors), addressable cache memories. The cache memory is a semiconductor memory and is provided to rapidly store data from the host computer/server before storage in the disk drives, and, on the other hand, store data from the disk drives prior to being sent to the host computer/server. The cache memory being a semiconductor memory, as distinguished from a magnetic memory as in the case of the disk drives, is much faster than the disk drives in reading and writing data.

The host computer/server controllers, disk controllers and cache memory are interconnected through a backplane printed circuit board. More particularly, disk controllers

are mounted on disk controller printed circuit boards. The host computer/server controllers are mounted on host computer/server controller printed circuit boards. And, cache memories are mounted on cache memory printed circuit boards. The disk directors, host computer/server directors, and cache memory printed circuit boards plug into the backplane printed circuit board. In order to provide data integrity in case of a failure in a director, the backplane printed circuit board has a pair of buses. One set the disk directors is connected to one bus and another set of the disk directors is connected to the other bus. Likewise, one set the host computer/server directors is connected to one bus and another set of the host computer/server directors is directors connected to the other bus. The cache memories are connected to both buses. Each one of the buses provides data, address and control information.

The arrangement is shown schematically in FIG. 1. Thus, the use of two buses B1, B2 provides a degree of redundancy to protect against a total system failure in the event that the controllers or disk drives connected to one bus, fail. Further, the use of two buses increases the data transfer bandwidth of the system compared to a system having a single bus. Thus, in operation, when the host computer/server 12 wishes to store data, the host computer 12 issues a write request to one of the front-end directors 14 (i.e., host computer/server directors) to perform a write command. One of the front-end directors 14 replies to the request and asks the host computer 12 for the data. After the request has passed to the requesting one of the front-end directors 14, the director 14 determines the size of the data and reserves space in the cache memory 18 to store the request. The front-end director 14 then produces control signals on one of the address memory busses B1, B2 connected to such front-end director 14 to enable the transfer to the cache memory 18. The host computer/server 12 then transfers the data to the front-end director 14. The front-end director 14 then advises the host computer/server 12 that the transfer is complete. The front-end director 14 looks up in a Table, not shown, stored in the cache memory 18 to determine which one of the back-end directors 20 (i.e., disk directors) is to handle this request. The Table maps the host computer/server 12 addresses into an address in the bank 14 of disk drives. The front-end director 14 then puts a notification in a "mail box" (not shown and stored in the cache memory 18) for the back-end director 20, which is to handle the request, the amount of the data and the disk address for the data. Other back-end directors 20 poll the cache memory 18 when they are idle to check their "mail boxes". If the polled "mail box" indicates a transfer is to be made, the back-end director 20 processes

the request, addresses the disk drive in the bank 22, reads the data from the cache memory 18 and writes it into the addresses of a disk drive in the bank 22.

When data is to be read from a disk drive in bank 22 to the host computer/server 12 the system operates in a reciprocal manner. More particularly, during a read operation, a read request is instituted by the host computer/server 12 for data at specified memory locations (i.e., a requested data block). One of the front-end directors 14 receives the read request and examines the cache memory 18 to determine whether the requested data block is stored in the cache memory 18. If the requested data block is in the cache memory 18, the requested data block is read from the cache memory 18 and is sent to the host computer/server 12. If the front-end director 14 determines that the requested data block is not in the cache memory 18 (i.e., a so-called "cache miss") and the director 14 writes a note in the cache memory 18 (i.e., the "mail box") that it needs to receive the requested data block. The back-end directors 20 poll the cache memory 18 to determine whether there is an action to be taken (i.e., a read operation of the requested block of data). The one of the back-end directors 20 which poll the cache memory 18 mail box and detects a read operation reads the requested data block and initiates storage of such requested data block stored in the cache memory 18. When the storage is completely written into the cache memory 18, a read complete indication is placed in the "mail box" in the cache memory 18. It is to be noted that the front-end directors 14 are polling the cache memory 18 for read complete indications. When one of the polling front-end directors 14 detects a read complete indication, such front-end director 14 completes the transfer of the requested data which is now stored in the cache memory 18 to the host computer/server 12.

The use of mailboxes and polling requires time to transfer data between the host computer/server 12 and the bank 22 of disk drives thus reducing the operating bandwidth of the interface.

SUMMARY OF THE INVENTION

In accordance with the present invention, a method is provided for producing a data storage system for transferring data between a host computer/server and a bank of disk drives through a system interface. The system interface has a plurality of first directors, a plurality of second directors, and a global memory. The method includes: providing a backplane having slots adapted to have plugged therein a plurality of printed circuit board. The printed circuit boards include: a plurality of first director boards having the first

directors; a plurality of second printed circuit boards having the second directors; a plurality of memory printed circuit boards providing the global memory; a plurality of dummy first director boards having first jumpers; a plurality of dummy second director boards having second jumpers; a plurality of dummy memory boards having third jumpers.

- 5 The method includes wiring the backplane to effect a connection among the first, second and third jumpers to interconnect the first plurality of director to the host computer/server, the plurality of second plurality of directors to the bank of disk drives and the global memory to the first plurality of directors and to the second plurality of director.

- In accordance with another feature of the invention, a data storage system is
10 provided for transferring data between a host computer/server and a bank of disk drives through a system interface. The system interface has a plurality of first directors, a plurality of second directors, and a global memory. The interface comprises: a backplane having slots adapted to have plugged therein a plurality of printed circuit board. The printed circuit boards comprise: a plurality of first director boards having the first
15 directors; a plurality of second printed circuit boards having the second directors; a plurality of memory printed circuit boards providing the global memory; a plurality of dummy first director boards having first jumpers; a plurality of dummy second director boards having second jumpers; a plurality of dummy memory boards having third jumpers. The backplane is wired to effect a connection among the first, second and third jumpers to
20 interconnect the first plurality of director to the host computer/server, the plurality of second plurality of directors to the bank of disk drives and the plurality of memories to the first plurality of directors and to the second plurality of director.

- In accordance with still another feature of the invention, a data storage system is provided for transferring data between a host computer/server and a bank of disk drives
25 through a system interface. The system interface includes: a plurality of first directors coupled to the host computer/server; a plurality of second directors coupled to the bank of disk drives; and, a cache memory. The cache memory includes: a common memory array having a pair of redundant data/control ports; and, a pair of logic networks each one coupled to a corresponding one of the pair of data/control ports. There are separate point-
30 to-point data paths between each one of the directors and the cache memory. A pair of the first directors are adapted for coupling to the pair of logic networks of the cache memory.

In one embodiment, each one of the first directors is on a different printed circuit board.

In accordance with another feature of the invention, a data storage system is provided for transferring data between a host computer/server and a bank of disk drives through a system interface. The system interface includes: a plurality of first directors coupled to the host computer/server; a plurality of second directors coupled to the bank of disk drives; and a cache memory. The cache memory has: a common memory array having a pair of redundant data/control ports; and a pair of logic networks each one coupled to a corresponding one of the pair of data/control ports. There are separate point-to-point data paths between each one of the directors and the global cache memory. A pair of the second directors are adapted for coupling to the pair of logic networks.

10 In one embodiment, each one of the pair of second directors is on a different printed circuit board.

In accordance with still another feature of the invention, a data storage system is provided for transferring data between a host computer/server and a bank of disk drives through a system interface. The interface includes: a plurality of first directors coupled to the host computer/server; a plurality of second directors coupled to the bank of disk drives; and a cache memory. The cache memory has a pair of memory boards, each memory board having a memory array. There are separate point-to-point data paths between each one of the directors and the global cache memory. One of the first directors is adapted for coupling to the memory arrays of the pair of memory boards.

20 In one embodiment, one of the second directors is adapted for coupling to the memory arrays of the pair of memory boards.

In one embodiment, each one of the memory boards has: a common memory array having a pair of redundant data/control ports; and, a pair of logic networks each one coupled to a corresponding one of the pair of data/control ports. The printed circuit board is wired to effect a connection with jumpers to enable a pair of the first directors to be coupled to the pair of logic networks and a pair of the second directors to be coupled to the pair of logic networks.

In one embodiment, the printed circuit board is wired to effect a connection with the jumpers to connect one of the first directors the memory arrays of a pair of the memory boards.

30 In one embodiment, the method includes providing each one of the directors on a different printed circuit board. The backplane is wired and connected to the jumpers to

connect each one of the pair of logic networks to one of the first directors and one of the second directors.

The details of one or more embodiments of the invention are set forth in the accompanying drawings and the description below. Other features, objects, and advantages of the invention will be apparent from the description and drawings, and from the claims.

DESCRIPTION OF DRAWINGS

These and other features of the invention will become more readily apparent from the following detailed description when read together with the accompanying drawings, in which:

FIG. 1 is a block diagram of a data storage system according to the PRIOR ART;

FIG. 2 is a block diagram of a data storage system according to the invention;

FIG. 3 is a sketch of an electrical cabinet storing a system interface used in the data storage system of FIG. 2;

FIG. 4 is a diagrammatical, isometric sketch showing printed circuit boards providing the system interface of the data storage system of FIG. 2;

FIG. 5 is a block diagram of the system interface used in the data storage system of FIG. 2;

FIG. 6 is a diagram of an exemplary global cache memory board used in the system interface of FIG. 2;

FIG. 6 A is a diagram showing an exemplary one of the memory printed circuit boards used in the system of FIG. 2;

FIG. 7 is a diagram showing a pair of front-end director boards coupled between a pair of host processors and global cache memory boards and a pair of front-end director boards coupled between a pair of disk drives and global cache memory boards used in the system interface of the system of FIG. 2;

FIG. 8 is an elevation view of a backplane used in the system of FIG. 2, such backplane having slots adapted to receive front-end director printed circuit boards, back-end director printed circuit boards and memory boards;

FIG. 9 is an elevation view of a backplane used in the system of FIG. 2, such backplane having slots adapted to receive front-end director printed circuit boards, back-end director printed circuit boards, memory boards and dummy front-end director printed

circuit boards, dummy back-end director printed circuit boards, dummy memory boards, such dummy printed circuit boards having jumpers to enable the same backplane to be used with a fully populated system having all of the memory boards and directors in FIG. 2 and a de-populated system having only a portion of the all of the memory boards and directors in FIG. 2;

FIG. 10 shows the dummy memory boards used in the de-populated system;

FIG. 11 shows the dummy director boards used in the de-populated system;

FIG. 12 A is a diagram showing an exemplary one of the memory printed circuit boards used in the de-populated system;

FIG. 13 is a diagram showing a pair of front-end director boards coupled between a pair of host processors and global cache memory boards and a pair of front-end director boards coupled between a pair of disk drives and global cache memory boards used in the system interface of the de-populated system; and

FIG. 14 is a universal director board adapted for use in the system interface of the de-populated system of FIG. 13.

DETAILED DESCRIPTION

Referring now to FIG. 2, a data storage system 100 is shown for transferring data between a host computer/server 120 and a bank of disk drives 140 through a system interface 160. The system interface 160 includes: a plurality of, here 32 front-end directors 180₁-180₃₂ coupled to the host computer/server 120 via ports 123₁-123₃₂; a plurality of back-end directors 200₁-200₃₂ coupled to the bank of disk drives 140 via ports 123₃₃-123₆₄; a data transfer section 240, having a global cache memory 220, coupled to the plurality of front-end directors 180₁-180₁₆ and the back-end directors 200₁-200₁₆; and a messaging network 260, operative independently of the data transfer section 240, coupled to the plurality of front-end directors 180₁-180₃₂ and the plurality of back-end directors 200₁-200₃₂, as shown. The front-end and back-end directors 180₁-180₃₂, 200₁-200₃₂ are functionally similar and include a microprocessor (μ P) 299 (i.e., a central processing unit (CPU) and RAM), a message engine/ CPU controller 314 and a data pipe 316, described in detail in the following co-pending patent applications:

<u>INVENTORS</u>	<u>FILING DATE</u>	<u>SERIAL NO.</u>	<u>TITLE</u>
Yuval Ofek et al.	March 31, 2000	09/540,828	Data Storage System Having Separate Data Transfer Section And Message Network
Paul C. Wilson et al.	June 29, 2000	09/606,730	Data Storage System Having Point-To-Point Configuration
John K. Walton et al.	January 22, 2002	10/054,241	Data Storage System (Divisional of 09/223,519 filed 12/30/1998)
Christopher S. MacLellan et al.	December 21, 2000	09/745,859	Data Storage System Having Plural Fault Domains
John K. Walton	May 17, 2001	09/859,659	Data Storage System Having No-Operation Command

Suffice it to say here, however, that the front-end and back-end directors 180₁-180₃₂, 200₁-200₃₂ control data transfer between the host computer/server 120 and the bank of disk drives 140 in response to messages passing between the directors 180₁-180₃₂, 200₁-200₃₂ through the messaging network 260. The messages facilitate the data transfer between host computer/server 120 and the bank of disk drives 140 with such data passing through the global cache memory 220 via the data transfer section 240. More particularly, in the case of the front-end directors 180₁-180₃₂, the data passes between the host computer to the global cache memory 220 through the data pipe 316 in the front-end directors 180₁-180₃₂ and the messages pass through the message engine/CPU controller 314 in such front-end directors 180₁-180₃₂. In the case of the back-end directors 200₁-200₃₂ the data passes between the back-end directors 200₁-200₃₂ and the bank of disk drives 140 and the global cache memory 220 through the data pipe 316 in the back-end directors 200₁-200₃₂ and again the messages pass through the message engine/CPU controller 314 in such back-end director 200₁-200₃₂.

With such an arrangement, the cache memory 220 in the data transfer section 240 is not burdened with the task of transferring the director messaging. Rather the messaging network 260 operates independent of the data transfer section 240 thereby increasing the operating bandwidth of the system interface 160.

In operation, and considering first a read request by the host computer/server 120 (i.e., the host computer/server 120 requests data from the bank of disk drives 140), the request is passed from one of a plurality of, here 32, host computer processors 121₁-121₃₂ in the host computer 120 to one or more of the pair of the front-end directors 180₁-180₃₂ connected to such host computer processor 121₁-121₃₂. (It is noted that in the host computer 120, each one of the host computer processors 121₁-121₃₂ is coupled to here a

pair (but not limited to a pair) of the front-end directors 180₁-180₃₂, to provide redundancy in the event of a failure in one of the front end-directors 181₁-181₃₂ coupled thereto.

Likewise, the bank of disk drives 140 has a plurality of, here 32, disk drives 141₁-141₃₂, each disk drive 141₁-141₃₂ being coupled to here a pair (but not limited to a pair) of the back-end directors 200₁-200₃₂, to provide redundancy in the event of a failure in one of the back-end directors 200₁-200₃₂ coupled thereto). Thus, front-end director pairs 180₁, 180₂; ... 180₃₁, 180₃₂ are coupled to processor pairs 121₁, 121₂; ... 121₃₁, 121₃₂, respectively, as shown. Likewise, back-end director pairs 200₁, 200₂; ... 200₃₁, 200₃₂ are coupled to disk drive pairs 141₁, 141₂; ... 141₃₁, 141₃₂, respectively, as shown.

Each front-end director 180₁-180₃₂ includes a microprocessor (μ P) 299 (i.e., a central processing unit (CPU) and RAM) described in detail in the referenced patent application. Suffice it to say here, however, that the microprocessor 299 makes a request for the data from the global cache memory 220. The global cache memory 220 has a resident cache management table, not shown. Every director 180₁-180₃₂, 200₁-200₃₂ has access to the resident cache management table and every time a front-end director 180₁-180₃₂ requests a data transfer, the front-end director 180₁-180₃₂ must query the global cache memory 220 to determine whether the requested data is in the global cache memory 220. If the requested data is in the global cache memory 220 (i.e., a read "hit"), the front-end director 180₁-180₃₂, more particularly the microprocessor 299 therein, mediates a DMA (Direct Memory Access) operation for the global cache memory 220 and the requested data is transferred to the requesting host computer processor 121₁-121₃₂.

If, on the other hand, the front-end director 180₁-180₃₂ receiving the data request determines that the requested data is not in the global cache memory 220 (i.e., a "miss") as a result of a query of the cache management table in the global cache memory 220, such front-end director 180₁-180₃₂ concludes that the requested data is in the bank of disk drives 140. Thus the front-end director 180₁-180₃₂ that received the request for the data must make a request for the data from one of the back-end directors 200₁-200₃₂ in order for such back-end director 200₁-200₃₂ to request the data from the bank of disk drives 140. The mapping of which back-end directors 200₁-200₃₂ control which disk drives 141₁-141₃₂ in the bank of disk drives 140 is determined during a power-up initialization phase. The map is stored in the global cache memory 220. Thus, when the front-end director 180₁-180₃₂ makes a request for data from the global cache memory 220 and determines that the requested data is not in the global cache memory 220 (i.e., a "miss"), the front-end director

180₁-180₃₂ is also advised by the map in the global cache memory 220 of the back-end director 200₁-200₃₂ responsible for the requested data in the bank of disk drives 140. The requesting front-end director 180₁-180₃₂ then must make a request for the data in the bank of disk drives 140 from the map designated back-end director 200₁-200₃₂. This request
5 between the front-end director 180₁-180₃₂ and the appropriate one of the back-end directors 200₁-200₃₂ (as determined by the map stored in the global cache memory 200) is by a message which passes from the front-end director 180₁-180₃₂ through the message network 260 to the appropriate back-end director 200₁-200₃₂. It is noted then that the message does not pass through the global cache memory 220 (i.e., does not pass through the data transfer
10 section 240) but rather passes through the separate, independent message network 260. Thus, communication between the directors 180₁-180₃₂, 200₁-200₃₂ is through the message network 260 and not through the global cache memory 220. Consequently, valuable bandwidth for the global cache memory 220 is not used for messaging among the directors 180₁-180₃₂, 200₁-200₃₂.

15 Thus, on a global cache memory 220 "read miss", the front-end director 180₁-180₃₂ sends a message to the appropriate one of the back-end directors 200₁-200₃₂ through the message network 260 to instruct such back-end director 200₁-200₃₂ to transfer the requested data from the bank of disk drives 140 to the global cache memory 220. When accomplished, the back-end director 200₁-200₃₂ advises the requesting front-end director
20 180₁-180₃₂ that the transfer is accomplished by a message, which passes from the back-end director 200₁-200₃₂ to the front-end director 180₁-180₃₂ through the message network 260. In response to the acknowledgement signal, the front-end director 180₁-180₃₂ is thereby advised that such front-end director 180₁-180₃₂ can transfer the data from the global cache memory 220 to the requesting host computer processor 121₁-121₃₂ as described above
25 when there is a cache "read hit".

It should be noted that there might be one or more back-end directors 200₁-200₃₂ responsible for the requested data. Thus, if only one back-end director 200₁-200₃₂ is responsible for the requested data, the requesting front-end director 180₁-180₃₂ sends a uni-cast message via the message network 260 to only that specific one of the back-end
30 directors 200₁-200₃₂. On the other hand, if more than one of the back-end directors 200₁-200₃₂ is responsible for the requested data, a multi-cast message (here implemented as a series of uni-cast messages) is sent by the requesting one of the front-end directors 180₁-180₃₂ to all of the back-end directors 200₁-200₃₂ having responsibility for the requested

data. In any event, with both a uni-cast or multi-cast message, such message is passed through the message network 260 and not through the data transfer section 240 (i.e., not through the global cache memory 220).

Likewise, it should be noted that while one of the host computer processors 121₁-121₃₂ might request data, the acknowledgement signal may be sent to the requesting host computer processor 121₁ or one or more other host computer processors 121₁-121₃₂ via a multi-cast (i.e., sequence of uni-cast) messages through the message network 260 to complete the data read operation.

Considering a write operation, the host computer 120 wishes to write data into storage (i.e., into the bank of disk drives 140). One of the front-end directors 180₁-180₃₂ receives the data from the host computer 120 and writes it into the global cache memory 220. The front-end director 180₁-180₃₂ then requests the transfer of such data after some period of time when the back-end director 200₁-200₃₂ determines that the data can be removed from such cache memory 220 and stored in the bank of disk drives 140. Before the transfer to the bank of disk drives 140, the data in the cache memory 220 is tagged with a bit as "fresh data" (i.e., data which has not been transferred to the bank of disk drives 140, that is data which is "write pending"). Thus, if there are multiple write requests for the same memory location in the global cache memory 220 (e.g., a particular bank account) before being transferred to the bank of disk drives 140, the data is overwritten in the cache memory 220 with the most recent data. Each time data is transferred to the global cache memory 220, the front-end director 180₁-180₃₂ controlling the transfer also informs the host computer 120 that the transfer is complete to thereby free-up the host computer 120 for other data transfers.

When it is time to transfer the data in the global cache memory 220 to the bank of disk drives 140, as determined by the back-end director 200₁-200₃₂, the back-end director 200₁-200₃₂ transfers the data from the global cache memory 220 to the bank of disk drives 140 and resets the tag associated with data in the global cache memory 220 (i.e., un-tags the data) to indicate that the data in the global cache memory 220 has been transferred to the bank of disk drives 140. It is noted that the un-tagged data in the global cache memory 220 remains there until overwritten with new data.

Referring now to FIGS. 3, 4, and 5, the system interface 160 is shown to include an electrical cabinet 300 having stored therein: a plurality of, here eight front-end director boards 190₁-190₈, each one having here four of the front-end directors 180₁-180₃₂; a

plurality of, here eight back-end director boards 210₁-210₈, each one having here four of the back-end directors 200₁-200₃₂; and a plurality of, here eight, memory boards M0- M7 which together make up the global cache memory 220. These boards plug into the front side of a backplane 302. (It is noted that the backplane 302 is a mid-plane printed circuit board). Plugged into the backside of the backplane 302 are message network boards which together make up the message network 260 as described in the co-pending patent applications referred to above. The backside of the backplane 302 has plugged into it adapter boards, not shown in FIGS. 2-4, which couple the boards plugged into the backside of the backplane 302 with the computer 120 and the bank of disk drives 140 as shown in FIG. 2.

That is, referring again briefly to FIG. 2, an I/O adapter, not shown, is coupled between each one of the front-end (FE) directors 180₁-180₃₂ and the host computer 120 and an I/O adapter, not shown, is coupled between each one of the back-end (BE) directors 200₁-200₃₂ and the bank of disk drives 140.

Referring now to FIG. 5, and as described in more in the co-pending patent applications referred to above, each one of the director boards 190₁-210₈ includes, as noted above four of the directors 180₁-180₃₂, 200₁-200₃₂ (FIG. 2). It is noted that the director boards 190₁-190₈ having four front-end directors per board, 180₁-180₃₂ are referred to as front-end directors, and the director boards 210₁-210₈ having four back-end directors per board, 200₁-200₃₂ are referred to as back-end directors. Each one of the directors 180₁-180₃₂, 200₁-200₃₂ includes the microprocessor 299 referred to above), the message engine/CPU controller 314, and the data pipe 316 shown in FIG. 2.

The front-end director boards have ports 123₁-123₃₂, as shown in FIG. 2, coupled to the processors 121₁-121₃₂, as shown. The back-end director boards have ports 123₃₃-123₆₄, as shown in FIG. 2, coupled to the disk drives 141₁-141₃₂, as shown.

Each one of the director boards 190₁-210₈ includes a crossbar switch 318 as shown in FIG. 5. The crossbar switch 318 has four input/output ports C₁-C₄, each one being coupled to the data pipe 316 (FIG. 2) of a corresponding one of the four directors 180₁-180₃₂, 200₁-200₃₂ on the director board 190₁-210₈. The crossbar switch 318 has eight output/input ports collectively identified in FIG. 5 by numerical designation 321 (which plug into the backplane 302). The crossbar switch 318 on the front-end director boards 191₁-191₈ is used for coupling the data pipe 316 of a selected one of the four front-end directors 180₁-180₃₂ on the front-end director board 190₁-190₈ to the global cache memory

220 via the backplane 302 and I/O adapter, not shown. The crossbar switch 318 on the back-end director boards 210₁-210₈ is used for coupling the data pipe 316 of a selected one of the four back-end directors 200₁-200₃₂ on the back-end director board 210₁-210₈ to the global cache memory 220 via the backplane 302 and I/O adapter, not shown. Thus, referring to FIG. 2, the data pipe 316 in the front-end directors 180₁-180₃₂ couples data between the host computer 120 and the global cache memory 220 while the data pipe 316 in the back-end directors 200₁-200₃₂ couples data between the bank of disk drives 140 and the global cache memory 220. It is noted that there are separate point-to-point data paths PTH₁-PTH₆₄ (FIG. 2) between each one of the directors 180₁-180₃₂, 200₁-200₃₂ and the global cache memory 220. It is also noted that the backplane 302 is a passive backplane because it is made up of only etched conductors on one or more layers of a printed circuit board. That is, the backplane 302 does not have any active components.

Further, as described in the co-pending patent applications referred to above, crossbar switch 320 (FIG. 5) plugs into the backplane 302 and is used for coupling to the directors to the message network 260 (FIG. 2) through the backplane.

Referring again to FIG. 5, the crossbar switch 318 includes a pair of crossbar switches 406X, 406Y. Each one of the switches 406X, 406Y includes four input/output director-side ports C₁-C₄ and the four input/output memory-side ports collectively designated in FIG. 5 by numerical designation 321. The director-side ports C₁-C₄ of switch 406X are connected to the four directors on the director board, as indicated, and as described in more detail in the co-pending patent applications referred to above. Likewise, director-side ports C₁-C₄ of switch 406Y are also connected to the dual-ported directors on such board, as indicated. Thus, as described in the co-pending patent applications referred to above, each director is a dual-ported directors.

Each one of the ports C₁-C₄ may be coupled to a selected one of the four ports collectively designated by 321 in accordance with control words provided to the switch 406X by the directors on such board, respectively, as described in the above-referenced patent application. Suffice it to say here, that port 402A of any one of the directors 180₁, 180₃, 180₅, 180₇ may be coupled to any one of the ports 321 of switch 406X, selectively in accordance with the control words. The coupling between the director boards 190₁-190₈, 210₁-210₈ and the global cache memory 220 is shown in FIG. 8. Likewise for switch 406Y.

More particularly, and referring also to FIG. 2, as noted above, each one of the host computer processors 121₁ - 121₃₂ in the host computer 120 is coupled to a pair of the front-end directors 180₁-180₃₂, to provide redundancy in the event of a failure in one of the front-end-directors 181₁-181₃₂ coupled thereto. Likewise, the bank of disk drives 140 has a plurality of, here 32, disk drives 141₁-141₃₂, each disk drive 141₁-141₃₂ being coupled to a pair of the back-end directors 200₁-200₃₂, to provide redundancy in the event of a failure in one of the back-end directors 200₁-200₃₂ coupled thereto). Thus, considering exemplary host computer processor 121₁, such processor 121₁ is coupled to a pair of front-end directors 180₁, 180₂. Thus, if director 180₁ fails, the host computer processor 121₁ can still access the system interface 160, albeit by the other front-end director 180₂. Thus, directors 180₁ and 180₂ are considered redundancy pairs of directors. Likewise, other redundancy pairs of front-end directors are: front-end directors 180₃, 180₄; 180₅, 180₆; 180₇, 180₈; 180₉, 180₁₀; 180₁₁, 180₁₂; 180₁₃, 180₁₄; 180₁₅, 180₁₆; 180₁₇, 180₁₈; 180₁₉, 180₂₀; 180₂₁, 180₂₂; 180₂₃, 180₂₄; 180₂₅, 180₂₆; 180₂₇, 180₂₈; 180₂₉, 180₃₀; and 180₃₁, 180₃₂ (only directors 180₃₁ and 180₃₂ being shown in FIG. 2).

Likewise, disk drive 141₁ is coupled to a pair of back-end directors 200₁, 200₂. Thus, if director 200₁ fails, the disk drive 141₁ can still access the system interface 160, albeit by the other back-end director 180₂. Thus, directors 200₁ and 200₂ are considered redundancy pairs of directors. Likewise, other redundancy pairs of back-end directors are: back-end directors 200₃, 200₄; 200₅, 200₆; 200₇, 200₈; 200₉, 200₁₀; 200₁₁, 200₁₂; 200₁₃, 200₁₄; 200₁₅, 200₁₆; 200₁₇, 200₁₈; 200₁₉, 200₂₀; 200₂₁, 200₂₂; 200₂₃, 200₂₄; 200₂₅, 200₂₆; 200₂₇, 200₂₈; 200₂₉, 200₃₀; and 200₃₁, 200₃₂ (only directors 200₃₁ and 200₃₂ being shown in FIG. 2).

As noted above, there are four directors on each one of the director boards. The physical position of the director boards along with a positional designation, are shown in FIG. 8 (e.g., director board 190₁ also has the designation D2). Further, Thus, referring to FIGS. 2 and 5:

FRONT -END DIRECTOR BOARD	FRONT-END DIRECTORS ON THE FRONT-END DIRECTOR BOARD
190 ₁ (D2)	180 ₁ , 180 ₃ , 180 ₅ , 180 ₇
190 ₁ (DD)	180 ₂ , 180 ₄ , 180 ₆ , 180 ₈
190 ₂ (D3)	180 ₉ , 180 ₁₁ , 180 ₁₃ , 180 ₁₅
190 ₃ (DC)	180 ₁₀ , 180 ₁₂ , 180 ₁₄ , 180 ₁₆
190 ₄ (D9)	180 ₁₇ , 180 ₁₉ , 180 ₂₁ , 180 ₂₃
190 ₅ (D6)	180 ₁₈ , 180 ₂₀ , 180 ₂₂ , 180 ₂₄
190 ₆ (D8)	180 ₂₅ , 180 ₂₇ , 180 ₂₉ , 180 ₃₁
190 ₇ (D7)	180 ₂₆ , 180 ₂₈ , 180 ₃₀ , 180 ₃₂

FRONT -END DIRECTOR BOARD	FRONT-END DIRECTORS ON THE FRONT-END DIRECTOR BOARD
210 ₁ (D0)	200 ₁ , 200 ₃ , 200 ₅ , 200 ₇
210 ₁ (DF)	200 ₂ , 200 ₄ , 200 ₆ , 200 ₈
210 ₂ (D2)	200 ₉ , 200 ₁₁ , 200 ₁₃ , 200 ₁₅
210 ₃ (DE)	200 ₁₀ , 200 ₁₂ , 200 ₁₄ , 200 ₁₆
210 ₄ (DB)	200 ₁₇ , 200 ₁₉ , 200 ₂₁ , 200 ₂₃
210 ₅ (D4)	200 ₁₈ , 200 ₂₀ , 200 ₂₂ , 200 ₂₄
210 ₆ (DA)	200 ₂₅ , 200 ₂₇ , 200 ₂₉ , 200 ₃₁
210 ₇ (D5)	200 ₂₆ , 200 ₂₈ , 200 ₃₀ , 200 ₃₂

Thus, to provide the redundant pairs of directors described above, the following
5 director boards are paired to enable achievement of the above-described redundancy:

Front-end boards:

D2 and DD

D3 and DC

D9 and D6

D8 and D7

10

Back-end boards

D0 and DF

D2 and DE

DB and D4

DA and D5

Further, referring also to FIG. 5, the global cache memory 220 includes a plurality
5 of, here eight, cache memory boards M0-M7, as shown. Still further, referring to FIG. 6,
an exemplary one of the cache memory boards is shown. Here, each cache memory board
includes four memory array regions 1-4, an exemplary one thereof being shown and
described in connection with FIG. 6 of U. S. Patent No. 5,943,287 entitled "Fault Tolerant
Memory System", John K. Walton, inventor, issued August 24, 1999 and assigned to the
10 same assignee as the present invention, the entire subject matter therein being incorporated
herein by reference. Further detail of the exemplary one of the cache memory boards is
described in the co-pending patent applications referred to above.

As shown in FIG. 6, the exemplary memory board includes a plurality of, here four
RAM memory array regions 1-4, each one of the array regions has a pair of redundant
15 data/control ports, i.e., an A port and a B port, for receiving data to, or from, the memory
array region as well as for receiving memory control signals. The memory board itself has
sixteen ports; a set of eight domain A ports P₀-P₇ and a set of eight domain B ports P₈-P₁₅.
As described in more detail in the co-pending patent applications referred to above and in
the above-reference U. S. Patent, each memory board has four logic networks (here
20 crossbar switches). These four logic networks 221_{1A}, 221_{2A}, 221_{1B}, 221_{2B}, are here cross
bar switches. Logic networks 221_{1A}, 221_{2A}, and logic networks 221_{1B}, 221_{2B}, are in two
independent domains, i.e., domain A and domain B. Thus, logic networks 221_{1A}, 221_{2A},
are in domain A and logic networks 221_{1B}, 221_{2B} are in domain B, respectively. Further,
logic networks 221_{1A}, 221_{2A}, in domain A are designated as A1 and A2 respectively, and
25 logic networks 221_{1B}, 221_{2B} in domain B are designated as B1 and B2, respectively.

These connections between memory boards M0 through M7 and directors D0
through DF are in the following Tables I and II, respectively:

TABLE I

PORT	MEMORY 0	DIRECTOR (END), PORT, SWITCH
	LOGIC	
P ₀	A1	D8 (FE), Port 0, Switch 406X
P ₁	A1	D0 (BE), Port 0, Switch 406X
P ₂	A1	D9 (FE), Port 1, Switch 406X
P ₃	A1	D1 (BE), Port 1, Switch 406X
P ₄	A2	DA (BE), Port 2, Switch 406X
P ₅	A2	D2 (FE), Port 2, Switch 406X
P ₆	A2	DB (BE), Port 3, Switch 406X
P ₇	A2	D3 (FE), Port 3, Switch 406X
P ₈	B1	DC (FE), Port 4, Switch 406Y
P ₉	B1	D4 (BE), Port 4, Switch 406Y
P ₁₀	B1	DD (FE), Port 5, Switch 406Y
P ₁₁	B1	D5 (BE), Port 5, Switch 406Y
P ₁₂	B2	DE (BE), Port 6, Switch 406Y
P ₁₃	B2	D6 (FE), Port 6, Switch 406Y
P ₁₄	B2	DF (BE), Port 7, Switch 406Y
P ₁₅	B2	D7 (FE), Port 7, Switch 406Y

PORT	MEMORY 1	DIRECTOR, PORT, SWITCH
	LOGIC	
P ₀	A1	DC (FE), Port 0, Switch 406X
P ₁	A1	D4 (BE), Port 0, Switch 406X
P ₂	A1	DD (FE), Port 1, Switch 406X
P ₃	A1	D5 (BE), Port 1, Switch 406X
P ₄	A2	DE (BE), Port 2, Switch 406X
P ₅	A2	D6 (FE), Port 2, Switch 406X
P ₆	A2	DF (BE), Port 3, Switch 406X
P ₇	A2	D7 (FE), Port 3, Switch 406X
P ₈	B1	D8 (FE), Port 4, Switch 406Y
P ₉	B1	D0 (BE), Port 4, Switch 406Y
P ₁₀	B1	D9 (FE), Port 5, Switch 406Y
P ₁₁	B1	D1 (BE), Port 5, Switch 406Y
P ₁₂	B2	DA (BE), Port 6, Switch 406Y
P ₁₃	B2	D2 (FE), Port 6, Switch 406Y
P ₁₄	B2	DB (BE), Port 7, Switch 406Y
P ₁₅	B2	D3 (FE), Port 7, Switch 406Y

MEMORY 2		
PORT	LOGIC	DIRECTOR, PORT, SWITCH
P ₀	A1	DF (BE), Port 0, Switch 406X
P ₁	A1	D1 (BE), Port 0, Switch 406X
P ₂	A1	D8 (FE), Port 1, Switch 406X
P ₃	A1	D2 (FE), Port 1, Switch 406X
P ₄	A2	D9 (FE), Port 2, Switch 406X
P ₅	A2	D3 (FE), Port 2, Switch 406X
P ₆	A2	DA (BE), Port 3, Switch 406X
P ₇	A2	D4 (BE), Port 3, Switch 406X
P ₈	B1	DB (BE), Port 4, Switch 406Y
P ₉	B1	D5 (BE), Port 4, Switch 406Y
P ₁₀	B1	DC (FE), Port 5, Switch 406Y
P ₁₁	B1	D6 (FE), Port 5, Switch 406Y
P ₁₂	B2	DD (FE), Port 6, Switch 406Y
P ₁₃	B2	D7 (FE), Port 6, Switch 406Y
P ₁₄	B2	DE (BE), Port 7, Switch 406Y
P ₁₅	B2	D0 (BE), Port 7, Switch 406Y

MEMORY 3		
PORT	LOGIC	DIRECTOR, PORT, SWITCH
P ₀	A1	DB (BE), Port 0, Switch 406X
P ₁	A1	D5 (BE), Port 0, Switch 406X
P ₂	A1	DC (FE), Port 1, Switch 406X
P ₃	A1	D6 (FE), Port 1, Switch 406X
P ₄	A2	DD (FE), Port 2, Switch 406X
P ₅	A2	D7 (FE), Port 2, Switch 406X
P ₆	A2	DE (BE), Port 3, Switch 406X
P ₇	A2	D0 (BE), Port 3, Switch 406X
P ₈	B1	DF (BE), Port 4, Switch 406Y
P ₉	B1	D1 (BE), Port 4, Switch 406Y
P ₁₀	B1	D8 (FE), Port 5, Switch 406Y
P ₁₁	B1	D2 (FE), Port 5, Switch 406Y
P ₁₂	B2	D9 (FE), Port 6, Switch 406Y
P ₁₃	B2	D3 (FE), Port 6, Switch 406Y
P ₁₄	B2	DA (BE), Port 7, Switch 406Y
P ₁₅	B2	D4 (BE), Port 7, Switch 406Y

	MEMORY 4	
PORT	LOGIC	DIRECTOR, PORT, SWITCH
P ₀	A1	DE (BE), Port 0, Switch 406X
P ₁	A1	D2 (FE), Port 0, Switch 406X
P ₂	A1	DF (BE), Port 1, Switch 406X
P ₃	A1	D3 (FE), Port 1, Switch 406X
P ₄	A2	D8 (FE), Port 2, Switch 406X
P ₅	A2	D4 (BE), Port 2, Switch 406X
P ₆	A2	D9 (FE), Port 3, Switch 406X
P ₇	A2	D5 (BE), Port 3, Switch 406X
P ₈	B1	DA (BE), Port 4, Switch 406Y
P ₉	B1	D6 (FE), Port 4, Switch 406Y
P ₁₀	B1	DB (BE), Port 5, Switch 406Y
P ₁₁	B1	D7 (FE), Port 5, Switch 406Y
P ₁₂	B2	DC (FE), Port 6, Switch 406Y
P ₁₃	B2	D0 (BE), Port 6, Switch 406Y
P ₁₄	B2	DD (FE), Port 7, Switch 406Y
P ₁₅	B2	D1 (BE), Port 7, Switch 406Y

	MEMORY 5	
PORT	LOGIC	DIRECTOR, PORT, SWITCH
P ₀	A1	DA (BE), Port 0, Switch 406X
P ₁	A1	D6 (FE), Port 0, Switch 406X
P ₂	A1	DB (BE), Port 1, Switch 406X
P ₃	A1	D7 (FE), Port 1, Switch 406X
P ₄	A2	DC (FE), Port 2, Switch 406X
P ₅	A2	D0 (BE), Port 2, Switch 406X
P ₆	A2	DD (FE), Port 3, Switch 406X
P ₇	A2	D1 (BE), Port 3, Switch 406X
P ₈	B1	DE (BE), Port 4, Switch 406X
P ₉	B1	D2 (FE), Port 4, Switch 406Y
P ₁₀	B1	DF (BE), Port 5, Switch 406Y
P ₁₁	B1	D3 (FE), Port 5, Switch 406Y
P ₁₂	B2	D8 (FE), Port 6, Switch 406Y
P ₁₃	B2	D4 (BE), Port 6, Switch 406Y
P ₁₄	B2	D9 (FE), Port 7, Switch 406Y
P ₁₅	B2	D5 (BE), Port 7, Switch 406Y

MEMORY 6		
PORT	LOGIC	DIRECTOR, PORT, SWITCH
P ₀	A1	DD (FE), Port 0, Switch 406X
P ₁	A1	D3 (FE), Port 0, Switch 406X
P ₂	A1	DE (BE), Port 1, Switch 406X
P ₃	A1	D4 (BE), Port 1, Switch 406X
P ₄	A2	DF (BE), Port 2, Switch 406X
P ₅	A2	D5 (BE), Port 2, Switch 406X
P ₆	A2	D8 (FE), Port 3, Switch 406X
P ₇	A2	D6 (FE), Port 3, Switch 406X
P ₈	B1	D9 (FE), Port 4, Switch 406Y
P ₉	B1	D7 (FE), Port 4, Switch 406Y
P ₁₀	B1	DA (BE), Port 5, Switch 406Y
P ₁₁	B1	D0 (BE), Port 5, Switch 406Y
P ₁₂	B2	DB (BE), Port 6, Switch 406Y
P ₁₃	B2	D1 (BE), Port 6, Switch 406Y
P ₁₄	B2	DC (FE), Port 7, Switch 406Y
P ₁₅	B2	D2 (FE), Port 7, Switch 406Y

MEMORY 7		
PORT	LOGIC	DIRECTOR, PORT, SWITCH
P ₀	A1	D9 (FE), Port 0, Switch 406X
P ₁	A1	D7 (FE), Port 0, Switch 406X
P ₂	A1	DA (BE), Port 1, Switch 406X
P ₃	A1	D0 (BE), Port 1, Switch 406X
P ₄	A2	DB (BE), Port 2, Switch 406X
P ₅	A2	D1 (BE), Port 2, Switch 406X
P ₆	A2	DC (FE), Port 3, Switch 406X
P ₇	A2	D2 (FE), Port 3, Switch 406X
P ₈	B1	DD (FE), Port 4, Switch 406Y
P ₉	B1	D3 (FE), Port 4, Switch 406Y
P ₁₀	B1	DE (BE), Port 5, Switch 406Y
P ₁₁	B1	D4 (BE), Port 5, Switch 406Y
P ₁₂	B2	DF (BE), Port 6, Switch 406Y
P ₁₃	B2	D5 (BE), Port 6, Switch 406Y
P ₁₄	B2	D8 (FE), Port 7, Switch 406Y
P ₁₅	B2	D6 (FE), Port 7, Switch 406Y

TABLE II

DIRECTOR	DIRECTOR PORT	CROSSBAR SWITCH	MEMORY BOARD	MEMORY BOARD PORT	MEMORY LOGIC NETWORK
D2	2	406X	M0	P5	A2
	1	406X	M2	P3	A1
	0	406X	M4	P1	A1
	3	406X	M7	P7	A2
	6	406Y	M1	P13	B2
	5	406Y	M3	P11	B1
	4	406Y	M5	P9	B1
	7	406Y	M6	P15	B2

DIRECTOR	DIRECTOR PORT	CROSSBAR SWITCH	MEMORY BOARD	MEMORY BOARD PORT	MEMORY LOGIC NETWORK
DD	5	406Y	M0	P10	B1
	6	406Y	M2	P12	B2
	7	406Y	M4	P14	B2
	4	406Y	M7	P8	B1
	1	406X	M1	P2	A1
	2	406X	M3	P4	A2
	3	406X	M5	P6	A2
	0	406X	M6	P0	A1

DIRECTOR	DIRECTOR PORT	CROSSBAR SWITCH	MEMORY BOARD	MEMORY BOARD PORT	MEMORY LOGIC NETWORK
D3	3	406X	M0	P7	A2
	2	406X	M2	P5	A2
	1	406X	M4	P3	A1
	0	406X	M6	P1	A1
	7	406Y	M1	P15	B2
	6	406Y	M3	P13	B2
	5	406Y	M5	P11	B1
	4	406Y	M7	P9	B1

5

DIRECTOR	DIRECTOR PORT	CROSSBAR SWITCH	MEMORY BOARD	MEMORY BOARD PORT	MEMORY LOGIC NETWORK
DC	4	406Y	M0	P8	B1
	5	406Y	M2	P10	B1
	6	406Y	M4	P12	B2
	7	406Y	M6	P14	B2
	0	406X	M1	P0	A1
	1	406X	M3	P2	A1
	2	406X	M5	P4	A2
	3	406X	M7	P6	A2

DIRECTOR	DIRECTOR PORT	CROSSBAR SWITCH	MEMORY BOARD	MEMORY BOARD PORT	MEMORY LOGIC NETWORK
D9	1	406X	M0	P2	A1
	2	406X	M2	P4	A2
	3	406X	M4	P6	A2
	0	406X	M7	P0	A1
	5	406Y	M1	P10	B1
	6	406Y	M3	P12	B2
	7	406Y	M5	P14	B2
	4	406Y	M6	P8	B1

DIRECTOR	DIRECTOR PORT	CROSSBAR SWITCH	MEMORY BOARD	MEMORY BOARD PORT	MEMORY LOGIC NETWORK
D6	6	406Y	M0	P13	B2
	5	406Y	M2	P11	B1
	4	406Y	M4	P9	B1
	7	406Y	M7	P15	B2
	2	406X	M1	P5	A2
	1	406X	M3	P3	A1
	0	406X	M5	P1	A1
	3	406X	M6	P7	A2

5

DIRECTOR	DIRECTOR PORT	CROSSBAR SWITCH	MEMORY BOARD	MEMORY BOARD PORT	MEMORY LOGIC NETWORK
D8	0	406X	M0	P0	A1
	1	406X	M2	P2	A1
	2	406X	M4	P4	A2
	3	406X	M6	P6	A2
	4	406Y	M1	P8	B1
	5	406Y	M3	P10	B1
	6	406Y	M5	P12	B2
	7	406Y	M7	P14	B2

DIRECTOR	DIRECTOR PORT	CROSSBAR SWITCH	MEMORY BOARD	MEMORY BOARD PORT	MEMORY LOGIC NETWORK
D7	7	406Y	M0	P15	B2
	6	406Y	M2	P13	B2
	5	406Y	M4	P11	B1
	4	406Y	M6	P9	B1
	3	406X	M1	P7	A2
	2	406X	M3	P5	A2
	1	406X	M5	P3	A1
	0	406X	M7	P1	A1

DIRECTOR	DIRECTOR PORT	CROSSBAR SWITCH	MEMORY BOARD	MEMORY BOARD PORT	MEMORY LOGIC NETWORK
DO	4	406Y	M1	P9	B1
	7	406Y	M2	P15	B2
	6	406Y	M4	P13	B2
	5	406Y	M6	P11	B1
	0	406X	M0	P1	A1
	3	406X	M3	P7	A2
	2	406X	M5	P5	A2
	1	406X	M7	P3	A1

DIRECTOR	DIRECTOR PORT	CROSSBAR SWITCH	MEMORY BOARD	MEMORY BOARD PORT	MEMORY LOGIC NETWORK
DF	7	406Y	M0	P14	B2
	0	406X	M2	P0	A1
	1	406X	M4	P2	A1
	2	406X	M6	P4	A2
	3	406X	M1	P6	A2
	4	406Y	M3	P8	B1
	5	406Y	M5	P10	B1
	6	406Y	M7	P12	B2

DIRECTOR	DIRECTOR PORT	CROSSBAR SWITCH	MEMORY BOARD	MEMORY BOARD PORT	MEMORY LOGIC NETWORK
DI	1	406X	M0	P3	A1
	0	406X	M2	1	A1
	7	406Y	M4	P15	B2
	6	406Y	M6	P13	B2
	5	406Y	M4	P11	B1
	4	406Y	M3	P9	B1
	3	406X	M5	P7	A2
	2	406X	M7	P5	A2

DIRECTOR	DIRECTOR PORT	CROSSBAR SWITCH	MEMORY BOARD	MEMORY BOARD PORT	MEMORY LOGIC NETWORK
DE	6	406Y	M0	P12	B2
	7	406Y	M2	P14	B2
	0	406X	M4	P0	A1
	1	406X	M6	P2	A1
	2	406X	M1	P4	A2
	3	406X	M3	P6	A2
	4	406Y	M5	P8	B1
	5	406Y	M7	P10	B1

DIRECTOR	DIRECTOR PORT	CROSSBAR SWITCH	MEMORY BOARD	MEMORY BOARD PORT	MEMORY LOGIC NETWORK
DB	3	406X	M0	P6	A2
	4	406Y	M2	P8	B1
	5	406Y	M4	P10	B1
	6	406Y	M6	P12	B2
	7	406Y	M1	P14	B2
	0	406X	M3	P6	A1
	1	406X	M5	P2	A1
	2	406X	M7	P4	A2

5

DIRECTOR	DIRECTOR PORT	CROSSBAR SWITCH	MEMORY BOARD	MEMORY BOARD PORT	MEMORY LOGIC NETWORK
D4	4	406Y	M0	P9	B1
	3	406X	M2	P7	A2
	2	406X	M4	P5	A2
	1	406X	M6	P3	A1
	0	406X	M1	P1	A1
	7	406Y	M3	P15	B2
	6	406Y	M5	P13	B2
	5	406Y	M7	P11	B1

DIRECTOR	DIRECTOR PORT	CROSSBAR SWITCH	MEMORY BOARD	MEMORY BOARD PORT	MEMORY LOGIC NETWORK
DA	2	406X	M0	P4	A2
	3	406X	M2	P6	A2
	4	406Y	M4	P8	B1
	5	406Y	M6	P10	B1
	6	406Y	M1	P12	B2
	7	406Y	M3	P14	B2
	0	406X	M5	P0	A1
	1	406X	M7	P2	A1

10

DIRECTOR	DIRECTOR PORT	CROSSBAR SWITCH	MEMORY BOARD	MEMORY BOARD PORT	MEMORY LOGIC NETWORK
D5	5	406Y	M0	P11	B1
	4	406Y	M2	P9	B1
	3	406X	M4	P7	A2
	2	406X	M6	P5	A2
	1	406X	M1	P3	A1
	0	406X	M3	P1	A1
	7	406Y	M5	P15	B2
	6	406Y	M7	P13	B2

From TABLE I above, it is noted that each one of the switches (i.e., logic networks A1, A2, B1 and B2) in each domain is connected to a pair of front end director boards a pair of back-end director boards. For example, for logic networks 221_{1A} (i.e., logic network A1), two of its port P₀ and P₂ are connected to one of the front-end director boards while the other two of its ports P₁ and P₃ are connected to one of the back-end director boards. Reference is made to FIG. 6A. This arrangement balances the loading on any one of the logic networks and thus increases the bandwidth of the system.

As noted above, the four switches (i.e., A1, A2, B1, B2) are in two independent domains, i.e., domain A and domain B, as shown in FIG. 6. Considering the exemplary four A ports P₀-P₃, each one of the four A ports P₀-P₃ can be coupled to the A port of any one of the memory array regions 1-4 through the logic network 221_{1A} (i.e., A1). Thus, considering port P₀, such port P₀ can be coupled to the A port of the four memory array regions 1-4. Likewise, considering the four A ports P₄-P₇ of logic network 221_{2A} (i.e., A2), each one of the four A ports P₄-P₇ can be coupled to the A port of any one of the memory array regions 1-4 through the logic network 221_{2A}. Likewise, considering the four B ports P₈-P₁₁ of logic network 221_{1B} (B1), each one of the four B ports P₈-P₁₁ can be coupled to the B port of any one of the memory array regions 1-4 through logic network 221_{1B}. Likewise, considering the four B ports P₁₂-P₁₅ of logic network 221_{2B} (B2), each one of the four B ports P₁₂-P₁₅ can be coupled to the B port of any one of the memory arrays through the logic network 221_{2B}. Thus, as described in the U. S. Patent referred to above, considering port P₁₂, such port can be coupled to the B port of the four memory array regions 1-4. Thus, there are two separate independent paths (i.e., domains) data and control from either a front-end director 180₁-180₃₂ or a back-end director 200₁-200₃₂ can reach each one of the four memory array regions 1-4 on the memory board. The logics A1 and A2 are in domain A and the logics B1 and B2 are in domain B.

Further, as noted above, each one of the directors has a pair of redundant ports, i.e. a 402A port and a 402 B port (FIG. 5). More particularly, referring to FIG. 7, an exemplary pair of redundant directors is shown, here, for example, front-end director 180₁ and front end-director 180₂. It is first noted that the directors 180₁, 180₂ in each redundant pair of directors must be on different director boards, here boards 190₁ (D2), 190₂ (DD), respectively. Thus, here front-end director boards 190₁-190₈ have thereon: front-end directors 180₁, 180₃, 180₅ and 180₇; front-end directors 180₂, 180₄, 180₆ and 180₈; front end directors 180₉, 180₁₁, 180₁₃ and 180₁₅; front end directors 180₁₀, 180₁₂, 180₁₄ and 180₁₆; front-end directors 180₁₇, 180₁₉, 180₂₁ and 180₂₃; front-end directors 180₁₈, 180₂₀, 180₂₂ and 180₂₄; front-end directors 180₂₅, 180₂₇, 180₂₉ and 180₃₁; front-end directors 180₁₈, 180₂₀, 180₂₂ and 180₂₄. Thus, here back-end director boards 210₁-210₈ have thereon: back-end directors 200₁, 200₃, 200₅ and 200₇; back-end directors 200₂, 200₄, 200₆ and 200₈; back-end directors 200₉, 200₁₁, 200₁₃ and 200₁₅; back-end directors 200₁₀, 200₁₂, 200₁₄ and 200₁₆; back-end directors 200₁₇, 200₁₉, 200₂₁ and 200₂₃; back-end directors 200₁₈, 200₂₀, 200₂₂ and 200₂₄; back-end directors 200₂₅, 200₂₇, 200₂₉ and 200₃₁; back-end directors 200₁₈, 200₂₀, 200₂₂ and 200₂₄ as discussed the two tables above.

Thus, here front-end director 180₁, shown in FIG. 7, is on front-end director board 190₁ (D2) and its redundant, or paired, front-end director 180₂, shown in FIG. 7, is on another front-end director board, here for example, front-end director board 190₂ (DD). As described above, and as described in more detail in the co-pending patent applications referred to above, each director has a pair of ports 402A, 402B, as shown in FIG. 6. Port 402A of the director is connected to switch 406X of crossbar switch 318 and the port 402B of the director is connected to switch 406Y of crossbar switch 318, as shown for director 180₁. Likewise, for redundant director 180₂.

The crossbar switch 318 has, as noted above, eight ports collectively referred to by numerical designation 321. These port ports plug into the backplane in the arrangement shown in FIG. 8. The eight ports for each one of the director boards are designated as 0, 1, 2, 3, 4, 5, 6 and 7, as shown. Ports 0, 1, 2 and 3 are ports of the X crossbar switch 406X and ports 4, 5, 6 and 7 are ports of the Y crossbar switch 406Y.

It is noted that, for each memory board M0-M7, the logic in domain A (A1 or A2) is connected to one of the redundant pair of director boards while the logic in the domain B (B1 or B2) is connected to the other one of the redundant pair of director boards. Thus,

here, for memory board M0, logic A2 is connected to director 180₁ of board D2 while logic B1 of memory board M0 is connected to director 180₂ of director board DD.

Further, it is noted that each director can be coupled to different domains of a pair of memory boards. For example, director 180₁ may be coupled to domain A (here logic A2) of memory board M0 through switch 406X and if such switch fails, to domain B (here logic B2) via switch 406Y on such director board DD.

Further, if director 180₁ fails, the memory M0 can be accessed via director 180₂. If domain A of memory M0 fails, the data in memory M0 can be accessed through its domain B logic through director 180₂. Thus, as stated more generally, each memory is accessible, via one of its domains, to one of a pair of directors and is also accessible, via its other domain, to the other one of the pair of directors. Further, it should be noted that each director is able to access a pair of memory boards. This later arrangement enables a dual write capability. That is, the data in a director may be written into memory boards. That is, with the arrangement shown, a director is able to write the same data into two different memories. Thus, for example, director 180₁ on board D2 can write data into memory M0 via switch 406X on board D2 and can write the same data into its paired memory M1 via switch 406Y on board D2. This is a dual-write feature with a point-to-point memory/director connection arrangement.

Finally it should be noted that each one of the paired host computer processors 121₁, 121₂ can access the same memory through either one of the paired directors D2, DD. Thus, for example if one of the paired director boards fails, say board D2, host computer processor 121₁ can access memory M0 through its paired director board DD. It is noted that this arrangement applies to the back-end directors as shown in FIG. 7 for paired back-end directors D0 and DF.

The slots in the wired backplane for the director printed circuit boards and memory printed circuit boards are shown in FIG. 8.

The connections to the ports of the director boards and the memory boards via the backplane are presented in the Tables I and II, above.

Consider now a customer for that data storage system requires only half the memory as that shown and described above in connection with FIG. 2. That is, instead of eight memory boards the customer requires four memory boards. However, it is desired that the system operate with the redundancy and dual write capability described above, but

with only four memory boards using the same backplane wiring as that for the eight memory board case described above.

To achieve this result, dummy memory boards and dummy directors are inserted into slots of the backplane otherwise occupied. These dummy boards do not have directors
 5 or memory arrays but rather have jumpers connected pair of ports of the dummy director board or dummy memory board, as the case may be, to be described. As will be shown, the use of these jumpers achieves the desired redundancy and dual write features described above.

Referring to FIG. 9, the slots in the backplane 302 are shown for a system having
 10 only 4 memory boards and eight director boards. Thus, here memory boards M2, M3, M4 and M 5 are replaced with dummy memory boards used in place of here memory boards M2, M3, M4 and M 5, as shown in FIG. 10. The jumpers are indicated by J, here eight jumpers J1-J8, being used to connect pairs of the memory board ports for each of the dummy memory boards used in place of memory boards M2, M3, M4 and M 5, as shown
 15 in FIG. 9. The connections provided by the jumpers for dummy memory boards M2, M3, M4 and M5 are:

P0 TO P8; P2 TO P10; P3 TO P11; P4 TO P12; P5 TO P13; P6 TO P14; and P7 TO P15, as shown in FIG. 10.

Likewise, as shown in FIG. 9, the slots in the backplane 302 occupied by director
 20 boards D9, D6, D8, D7, DB, D4, DA and D5 in a fully populated system are replaced with dummy director boards shown in FIG. 11. The jumpers are indicated by J, here eight jumpers J1-J8, being used to connect pairs of the director board ports for each of the dummy director boards used in place of director boards D9, D6, D8, D7, DB, D4, DA AND D5, as shown in FIG. 12. The connections provided by the jumpers for directors
 25 boards D9, D6, DB and D4 are: PORT 0 TO PORT 7; PORT 1 TO PORT 6; PORT 2 TO PORT 5; and PORT 3 TO PORT 4 while connections provided by the jumpers for directors boards D8, DA, D7 and D5 are PORT 0 TO PORT 5; PORT 1 TO PORT 4; PORT 2 TO PORT 7; and PORT 3 TO PORT 6. as shown in FIG. 11.

These jumpers result in connections between memory boards M0, M1, M6 and M7
 30 and directors D0, D1, D2, D3, DC, DD, DE AND DF are in the following Tables II and IV, respectively, below:

TABLE III

MEMORY 0			
PORT	LOGIC	DIRECTOR (END), PORT, SWITCH	PATH
P ₀	A1	DC (FE), Port 1, Switch 406X	D8 PORT 0, D8 PORT 5; M3, P10; M3, P2
P ₁	A1	D0 (BE), Port 0, Switch 406X	DIRECT
P ₂	A1	DD (FE), Port 2, Switch 406X	D9 PORT 1; D9 PORT 6; M3, P12; M3, P4
P ₃	A1	D1 (BE), Port 1, Switch 406X	DIRECT
P ₄	A2	DE (BE), Port 3, Switch 406X	DA PORT 2; DA PORT 7; M3, P14; M3, P6;
P ₅	A2	D2 (FE), Port 2, Switch 406X	DIRECT
P ₆	A2	DF (BE), Port 0, Switch 406X	DB PORT 3; DB PORT 4; M2, P8; M2, P0
P ₇	A2	D3 (FE), Port 3, Switch 406X	DIRECT
P ₈	B1	DC (FE), Port 4, Switch 406Y	DIRECT
P ₉	B1	D0 (BE), Port 7, Switch 406Y	D4 PORT 4; D4 PORT 3; M2, P7; M2, P15
P ₁₀	B1	DD (FE), Port 5, Switch 406Y	DIRECT
P ₁₁	B1	D1 (BE), Port 4, Switch 406Y	D5 PORT 5; D5 PORT 0; M3, P1; M3, P4
P ₁₂	B2	DE (BE), Port 6, Switch 406Y	DIRECT
P ₁₃	B2	D2 (FE), Port 5, Switch 406Y	D6 PORT 6; D6 PORT 1; M3, P3; M3, P11
P ₁₄	B2	DF (BE), Port 7, Switch 406Y	DIRECT
P ₁₅	B2	D3 (FE), Port 6, Switch 406Y	D7 PORT 7; D7 PORT 2; M3, P5; M3, P13

5

MEMORY 1			
PORT	PORT	DIRECTOR, PORT, SWITCH	PATH
P ₀	A1	DC (FE), Port 0, Switch 406X	DIRECT
P ₁	A1	D0 (BE), Port 3, Switch 406X	D4 PORT 0; D4 PORT 7; M3, P15; M3, P7
P ₂	A1	DD (FE), Port 1, Switch 406X	DIRECT
P ₃	A1	D1 (BE), Port 0, Switch 406X	D5 PORT 1; D5 PORT 4; M2, P9; M2, P1
P ₄	A2	DE (BE), Port 2, Switch 406X	DIRECT
P ₅	A2	D2 (FE), Port 1, Switch 406X	D6 PORT 2; D6 PORT 5; M2, P11; M2, P3
P ₆	A2	DF (BE), Port 3, Switch 406X	DIRECT
P ₇	A2	D3 (FE), Port 2, Switch 406X	D7 PORT 3; D7 PORT 6; M2, P13; M2, P5
P ₈	B1	DC (FE), Port 5, Switch 406Y	D8 PORT 4; D8 PORT 1; M2, P2; M2, P10
P ₉	B1	D0 (BE), Port 4, Switch 406Y	DIRECT
P ₁₀	B1	DD (FE), Port 6, Switch 406Y	D9 PORT 5; D9 PORT 2; M2, P4; M2, P12
P ₁₁	B1	D1 (BE), Port 5, Switch 406Y	DIRECT
P ₁₂	B2	DE (BE), Port 7, Switch 406Y	DA PORT 6; DA PORT 3; M2, P6; M2, P4
P ₁₃	B2	D2 (FE), Port 6, Switch 406Y	DIRECT
P ₁₄	B2	DF (BE), Port 4, Switch 406Y	DB PORT 7; DB PORT 0; M3, P0; M3, P8
P ₁₅	B2	D3 (FE), Port 7, Switch 406Y	DIRECT

DUMMY MEMORY 2			
PORT	PORT	DIRECTOR, PORT, SWITCH/JUMPER	
P ₀	P ₈	DF (BE), Port 0, Switch 406X	
P ₁	P ₉	D1 (BE), Port 0, Switch 406X	
P ₂	P ₁₀	D8 (FE), Port 1, Jumper	
P ₃	P ₁₁	D2 (FE), Port 1, Switch 406X	
P ₄	P ₁₂	D9 (FE), Port 2, Jumper	
P ₅	P ₁₃	D3 (FE), Port 2, Switch 406X	
P ₆	P ₁₄	DA (BE), Port 3, Jumper	
P ₇	P ₁₅	D4 (BE), Port 3, Jumper	
P ₈	P ₀	DB (BE), Port 4, Jumper	
P ₉	P ₁	D5 (BE), Port 4, Jumper	
P ₁₀	P ₂	DC (FE), Port 5, Switch 406Y	
P ₁₁	P ₃	D6 (FE), Port 5, Jumper	
P ₁₂	P ₄	DD (FE), Port 6, Switch 406Y	
P ₁₃	P ₅	D7 (FE), Port 6, Jumper	
P ₁₄	P ₆	DE (BE), Port 7, Switch 406Y	
P ₁₅	P ₇	D0 (BE), Port 7, Switch 406Y	

5

DUMMY MEMORY 3			
PORT	PORT	DIRECTOR, PORT, SWITCH/JUMPER	
P ₀	P ₈	DB (BE), Port 0, Jumper	
P ₁	P ₉	D5 (BE), Port 0, Jumper	
P ₂	P ₁₀	DC (FE), Port 1, Switch 406X	
P ₃	P ₁₁	D6 (FE), Port 1, Jumper	
P ₄	P ₁₂	DD (FE), Port 2, Switch 406X	
P ₅	P ₁₃	D7 (FE), Port 2, Jumper	
P ₆	P ₁₄	DE (BE), Port 3, Switch 406X	
P ₇	P ₁₅	D0 (BE), Port 3, Switch 406X	
P ₈	P ₀	DF (BE), Port 4, Switch 406Y	
P ₉	P ₁	D1 (BE), Port 4, Switch 406Y	
P ₁₀	P ₂	D8 (FE), Port 5, Jumper	
P ₁₁	P ₃	D2 (FE), Port 5, Switch 406Y	
P ₁₂	P ₄	D9 (FE), Port 6, Jumper	
P ₁₃	P ₅	D3 (FE), Port 6, Switch 406Y	
P ₁₄	P ₆	DA (BE), Port 7, Jumper	
P ₁₅	P ₇	D4 (BE), Port 7, Jumper	

DUMMY MEMORY 4			
PORT		DIRECTOR, PORT, SWITCH/JUMPER	
P ₀	P ₈	DE (BE), Port 0, Switch 406X	
P ₁	P ₉	D2 (FE), Port 0, Switch 406X	
P ₂	P ₁₀	DF (BE), Port 1, Switch 406X	
P ₃	P ₁₁	D3 (FE), Port 1, Switch 406X	
P ₄	P ₁₂	D8 (FE), Port 2, Jumper	
P ₅	P ₁₃	D4 (BE), Port 2, Jumper	
P ₆	P ₁₄	D9 (FE), Port 3, Jumper	
P ₇	P ₁₅	D5 (BE), Port 3, Jumper	
P ₈	P ₀	DA (BE), Port 4, Jumper	
P ₉	P ₁	D6 (FE), Port 4, Jumper	
P ₁₀	P ₂	DB (BE), Port 5, Jumper	
P ₁₁	P ₃	D7 (FE), Port 5, Jumper	
P ₁₂	P ₄	DC (FE), Port 6, Switch 406Y	
P ₁₃	P ₅	D0 (BE), Port 6, Switch 406Y	
P ₁₄	P ₆	DD (FE), Port 7, Switch 406Y	
P ₁₅	P ₇	D1 (BE), Port 7, Switch 406Y	

5

DUMMY MEMORY 5			
PORT	PORT	DIRECTOR, PORT, SWITCH/JUMPER	
P ₀	P ₈	DA (BE), Port 0, Jumper	
P ₁	P ₉	D6 (FE), Port 0, Jumper	
P ₂	P ₁₀	DB (BE), Port 1, Jumper	
P ₃	P ₁₁	D7 (FE), Port 1, Jumper	
P ₄	P ₁₂	DC (FE), Port 2, Switch 406X	
P ₅	P ₁₃	D0 (BE), Port 2, Switch 406X	
P ₆	P ₁₄	DD (FE), Port 3, Switch 406X	
P ₇	P ₁₅	D1 (BE), Port 3, Switch 406X	
P ₈	P ₀	DE (BE), Port 4, Switch 406Y	
P ₉	P ₁	D2 (FE), Port 4, Switch 406Y	
P ₁₀	P ₂	DF (BE), Port 5, Switch 406Y	
P ₁₁	P ₃	D3 (FE), Port 5, Switch 406Y	
P ₁₂	P ₄	D8 (FE), Port 6, Jumper	
P ₁₃	P ₅	D4 (BE), Port 6, Jumper	
P ₁₄	P ₆	D9 (FE), Port 7, Jumper	
P ₁₅	P ₇	D5 (BE), Port 7, Jumper	

MEMORY 6			
PORT	LOGIC	DIRECTOR, PORT, SWITCH	PATH
P ₀	A1	DD (FE), Port 0, Switch 406X	DIRECT
P ₁	A1	D3 (FE), Port 0, Switch 406X	DIRECT
P ₂	A1	DE (BE), Port 1, Switch 406X	DIRECT
P ₃	A1	D0 (BE), Port 2, Switch 406X	D4 PORT 1; D4 PORT 6; M5, P13; M5, P5
P ₄	A2	DF (BE), Port 2, Switch 406X	DIRECT
P ₅	A2	D1 (BE), Port 3, Switch 406X	D5 PORT 2; D5 PORT 7; M5, P15; M5, P7
P ₆	A2	DC (FE), Port 2, Switch 406X	D8 PORT 5; D8 PORT 6; M5, P12; M5, P4
P ₇	A2	D2 (FE), Port 0, Switch 406X	D6 PORT 3; D6 PORT 4; M4, P9; M4, P1
P ₈	B1	DD (FE), Port 7, Switch 406Y	D9 PORT 4; D9 PORT 3; M4, P6; M4, P14
P ₉	B1	D3 (FE), Port 5, Switch 406Y	D7 PORT 4; D7 PORT 1; M5, P3; M5, P11
P ₁₀	B1	DE (BE), Port 4, Switch 406Y	DA PORT 5; DA PORT 0; M5, P0; M5, P8
P ₁₁	B1	D0 (BE), Port 5, Switch 406Y	DIRECT
P ₁₂	B2	DF (BE), Port 5, Switch 406Y	DB PORT 6; DB PORT 4; M5, P2; M5, P10
P ₁₃	B2	D1 (BE), Port 6, Switch 406Y	DIRECT
P ₁₄	B2	DC (FE), Port 7, Switch 406Y	DIRECT
P ₁₅	B2	D2 (FE), Port 7, Switch 406Y	DIRECT

6

5

MEMORY 7			
PORT	LOGIC	DIRECTOR, PORT, SWITCH	PATH
P ₀	A1	DD (FE), Port 3, Switch 406Y	D9 PORT 0; D9 PORT 7; M5, P14; M5, P6
P ₁	A1	D3 (FE), Port 1, Switch 406X	D7 PORT 4; D7 PORT 1; M5, P3; M5, P11
P ₂	A1	DE (BE), Port 0, Switch 406X	DA PORT 1; DA PORT 4; M4, P8; M4, P0
P ₃	A1	D0 (BE), Port 1, Switch 406X	DIRECT
P ₄	A2	DF (BE), Port 1, Switch 406X	DB PORT 2; DB PORT 5; M4, P10; M4, P2
P ₅	A2	D1 (BE), Port 2, Switch 406X	DIRECT
P ₆	A2	DC (FE), Port 3, Switch 406X	DIRECT
P ₇	A2	D2 (FE), Port 3, Switch 406X	DIRECT
P ₈	B1	DD (FE), Port 4, Switch 406Y	DIRECT
P ₉	B1	D3 (FE), Port 4, Switch 406Y	DIRECT
P ₁₀	B1	DE (BE), Port 5, Switch 406Y	DIRECT
P ₁₁	B1	D0 (BE), Port 6, Switch 406Y	D4 PORT 5; D4 PORT 2; M4, P5; M4, P13
P ₁₂	B2	DF (BE), Port 6, Switch 406Y	DIRECT
P ₁₃	B2	D1 (BE), Port 7, Switch 406Y	D5 PORT 6; D5 PORT 3; M4, P7; M4, P15
P ₁₄	B2	DC (FE), Port 6, Switch 406Y	D8 PORT 7; D8 PORT 2; M4, P4; M4, P12
P ₁₅	B2	D2 (FE), Port 4, Switch 406Y	D6, PORT 7; D6 PORT 0; M5, P1; M5, P9

TABLE IV

DIRECTOR	DIRECTOR PORT	CROSSBAR SWITCH	MEMORY BOARD	MEMORY BOARD PORT	MEMORY LOGIC NETWORK
D2	2	406X	M0	P5	A2
	1	406X	M1	P5	A2
	0	406X	M6	P7	A2
	7	406Y	M6	P15	B2
	6	406Y	M1	P13	B2
	5	406Y	M0	P13	B2
	4	406Y	M7	P15	B2
	3	406X	M7	P7	A2

DIRECTOR	DIRECTOR PORT	CROSSBAR SWITCH	MEMORY BOARD	MEMORY BOARD PORT	MEMORY LOGIC NETWORK
DD	5	406Y	M0	P10	B1
	6	406Y	M1	P10	B1
	7	406Y	M6	P8	B1
	0	406X	M6	P0	A1
	1	406X	M1	P2	A1
	2	406X	M0	P2	A1
	3	406X	M7	P0	A1
	4	406Y	M7	P8	B1

5

DIRECTOR	DIRECTOR PORT	CROSSBAR SWITCH	MEMORY BOARD	MEMORY BOARD PORT	MEMORY LOGIC NETWORK
D3	3	406X	M0	P7	A2
	2	406X	M1	P7	A2
	1	406X	M7	P1	A1
	0	406X	M6	P1	A1
	7	406Y	M1	P15	B2
	6	406Y	M0	P15	B2
	5	406Y	M6	P9	B1
	4	406Y	M7	P9	B1

10

DIRECTOR	DIRECTOR PORT	CROSSBAR SWITCH	MEMORY BOARD	MEMORY BOARD PORT	MEMORY LOGIC NETWORK
DC	4	406Y	M0	P8	B1
	5	406Y	M1	P8	B1
	6	406Y	M7	P14	B2
	7	406Y	M6	P14	B2
	0	406X	M1	P0	A1
	1	406X	M0	P0	A1
	2	406X	M0	P6	A2
	3	406X	M7	P6	A2

DIRECTOR	DIRECTOR PORT	CROSSBAR SWITCH	MEMORY BOARD	MEMORY BOARD PORT	MEMORY LOGIC NETWORK
DO	0	406X	M0	P1	A1
	7	406Y	M0	P9	B1
	6	406Y	M7	P11	B1
	5	406Y	M6	P11	B1
	4	406Y	M1	P9	B1
	3	406X	M1	P1	A1
	2	406X	M6	P3	A1
	1	406X	M7	P3	A1

5

DIRECTOR	DIRECTOR PORT	CROSSBAR SWITCH	MEMORY BOARD	MEMORY BOARD PORT	MEMORY LOGIC NETWORK
DF	7	406Y	M0	P14	B2
	0	406X	M0	P6	A2
	1	406X	M7	P4	A2
	2	406X	M6	P4	A2
	3	406X	M1	P6	A2
	4	406Y	M1	P14	B2
	5	406Y	M6	P12	B2
	6	406Y	M7	P12	B2

DIRECTOR	DIRECTOR PORT	CROSSBAR SWITCH	MEMORY BOARD	MEMORY BOARD PORT	MEMORY LOGIC NETWORK
DI	1	406X	M0	P3	A1
	0	406X	M1	P3	A1
	7	406Y	M7	P13	A2
	6	406Y	M6	P13	B2
	5	406Y	M1	P11	B1
	4	406Y	M0	P11	P11
	3	406X	M6	P5	A2
	2	406X	M7	P5	A2

10

DIRECTOR	DIRECTOR PORT	CROSSBAR SWITCH	MEMORY BOARD	MEMORY BOARD PORT	MEMORY LOGIC NETWORK
DE	6	406Y	M0	P12	B2
	7	406Y	M1	P12	B2
	0	406X	M7	P2	A1
	1	406X4	M6	P2	A1
	2	406X	M1	P4	A2
	3	406X	M0	P4	A2
	4	406Y	M6	P10	B1
	5	406Y	M7	P10	B1

It should be noted that the redundancy and dual write features of a fully populated system, described in detail in FIG. 7 are features retained in the de-populated system, here with only 4 memory boards and 8 director boards. Further, it will be noted that in this de-populated system, each logic network on the memory board is coupled to a pair of front end directors and a pair of back end directors as shown from the TABLES III and IV above.

More particularly, as noted above, each one of the directors has a pair of redundant ports, i.e., 402A port and 402 B port (FIG. 5). Thus, referring to FIG. 13 for the 4 memory/8 director system (referred to as the de-populated system), an exemplary pair of redundant directors is shown, here, for example, front-end director 180₁ and front end-director 180₂. It is first noted that the directors 180₁, 180₂ in each redundant pair of directors are again on different director boards, here boards 190₁ (D2), 190₂ (DD), respectively. Thus, here front-end director 180₁, shown in FIG. 15, is on front-end director board 190₁ (D2) and its redundant front-end director 180₂, shown in FIG. 13, is on another front-end director board, here for example, front-end director board 190₂ (DD). As described above, each director has a pair of ports 402A, 402B, as shown in FIG. 15. Port 402A of the director is connected to switch 406X of crossbar switch 318 and the port 402B of the director is connected to switch 406Y of crossbar switch 318, as shown for director 180₁. Likewise, for redundant director 180₂.

The crossbar switch 318 has, as noted above, eight ports collectively referred to by numerical designation 321. These port ports plug into the backplane in the arrangement shown in FIG.9. The eight ports for each one of the director boards are designated as 0, 1, 2, 3, 4, 5, 6 and 7, as shown. Ports 0, 1, 2 and 3 are ports of the X crossbar switch 406X and ports 4, 5, 6 and 7 are ports of the Y crossbar switch 406Y.

It is noted that because of the jumpers on the memory boards and director boards described above, instead of the eight ports of the director board being coupled to memory elements (i.e., memory regions 1-4) on eight memory board, here they are connected to only four memory boards. Thus, referring to FIG. 13, director board D2 and paired
5 director board DD are each connected only four memory boards, here memory boards M0, M1, M6 and M7, as shown.

Further, it is noted that each director can be coupled to different domains of a pair of memory boards. For example, director 180₁ on director board D2 may be coupled to domain A (here logic A2) of memory board M0 through switch 406X and if such switch
10 fails, to domain B (here logic B2) of memory board M0 through switch 406Y on such director board D2.

Further, if director 180₁ fails, the memory M0 can be accessed via director 180₂. If domain A of memory M0 fails, the data in memory M0 can be accessed through its domain B logic through director 180₂. Thus, as stated more generally, each memory is accessible,
15 via one of its domains, to one of a pair of directors and is also accessible, via its other domain, to the other one of the pair of directors. Further, it should be noted that each director is able to access a pair of memory boards. This later arrangement enables a dual write capability. That is, the data in a director may be written into memory boards. That is, with the arrangement shown, a director is able to write the same data into two different
20 memories. Thus, for example, director 180₁ on board D2 can write data into memory M0 via switch 406X on board D2 and can write the same data into its paired memory M1 via switch 406Y on board D2. This is a dual-write feature with a point-to-point memory/director connection arrangement.

It should be noted that each one of the paired host computer processors 121₁, 121₂
25 can access the same memory through either one of the paired directors D2, DD. Thus, for example if one of the paired director boards fails, say board D2, host computer processor 121₁ can access memory M0 through its paired director board DD.

It is noted that this arrangement applies to the back-end directors as shown in FIG.,
7 for paired back-end directors D0 and DF.

30 It is first noted that, referring to FIG. 10, all dummy (jumper) memory boards have the same jumper arrangement. It is next noted from FIG. 11, that the jumper arrangements used for director boards D9, DB, D6, and D4 are the same. Here all such director boards D9, DB, D6, and D4 have the jumpers arranged in a hereinafter referred to type "A"

configuration. Further, the jumper arrangements for director boards D8, DA, D7 and D5 are the same. Here all such director boards D8, DA, D7 and D5 have the jumpers arranged in a hereinafter referred to different type "B" configuration.

Referring now to FIG. 14, a universal dummy (jumper) director board UD is shown. It should be noted from FIG. 9 that all of the slots in the backplane for the director boards and the memory boards have a unique slot designation. More particularly, the slot designations from left to right are slot 0 through slot 23, as indicated. (This same slot designation applies to the fully populated backplane shown FIG. 8). Thus, the backplane has pins, not shown, hardwired to a 5-bit code representative of the slot designation. Thus, when director D0 plugs into slot 0 of the backplane, such director receives a binary code 00000. Likewise, when memory board M0 is plugged into slot 8 of the backplane provides the code 01000 to the memory board. And so forth for the other director boards and the memory boards.

Referring again to FIG. 14, the universal dummy director (i.e., jumper board) has three switches S1, S2, S3, S4 controlled and a decoder. When the universal board is plugged into a backplane slot, if the decoder thereon detects a code indicating that it is plugged into any of the slots: 17 (i.e., a D9 slot); 19 (i.e., a DB slot); slot 6 (i.e., a D6 slot); or slot 4 (i.e., a D4 slot), a logic 1 is produced by the decoder thereby placing the switches S1, S2, S3 and S4, in a type "A" configuration. When the universal board is plugged into a backplane slot, if the decoder detects that it is plugged into any of the slots: 16 (i.e., a D8 slot); 18 (i.e., a DA slot); slot 7 (i.e., a D7 slot); or slot 5 (i.e., a D5 slot), a logic 0 is produced by the decoder placing the switches S1, S2, S3 and S4 in a type "B" configuration.

In the type "A" condition, the switches S1, S2, S3 and S4, connect: port 0 to port 7; port 1 to port 6, port 2 to port 5; and port 3 to port 4, respectively. When in the type "B" condition, the switches S1, S2, S3 and S4, connect: port 0 to port 5; port 1 to port 4, port 2 to port 7; and port 3 to port 6, respectively. Thus, same universal board UD may be used for any director having jumpers.

Thus, a universal director board UD may be inserted into slots 4, 5, 6, 7, 16, 17, 18 and 19 and the decoders thereon will automatically active the switches S1, S2, S3, S4 to configure the universal boards to those shown in FIG. 11, described above.

It is noted that the signals passing through the director boards are here positive emitter coupled logic (PECL) signals. Further, it is to be noted that the switches S1, S2

and S3 are also used rebuffer these signals. Here, the switches S1, S2 and S3 are model VCS-830 switches by Vitesse Semiconductor Corporation, 741 Calle Plano, Camarillo, CA 93012.

Other embodiments are within the spirit and scope of the appended claims.

5 What is claimed is:

1 1. A data storage system for transferring data between a host computer/server
2 and a bank of disk drives through a system interface, such system interface comprising:
3 a plurality of first directors coupled to the host computer/server;
4 a plurality of second directors coupled to the bank of disk drives;
5 a cache memory, such cache memory having:
6 a common memory array having a pair of redundant data/control
7 ports;
8 a pair of logic networks each one coupled to a corresponding one of
9 the pair of data/control ports;
10 wherein there are separate point-to-point data paths between each one of the
11 directors and the global cache memory; and
12 wherein a pair of the first directors are adapted for coupling to the pair of
13 logic networks.

1 2. The system recited in claim 1 including a backplane and wherein the cache
2 memory and the directors are interconnected through the backplane.

1 3. The system recited in claim 2 wherein each one of the first directors is on a
2 different printed circuit board.

1 4. A data storage system for transferring data between a host computer/server
2 and a bank of disk drives through a system interface, such system interface comprising:
3 a plurality of first directors coupled to the host computer/server;
4 a plurality of second directors coupled to the bank of disk drives;
5 a cache memory, such cache memory having:
6 a common memory array having a pair of redundant data/control
7 ports;
8 a pair of logic networks each one coupled to a corresponding one of
9 the pair of data/control ports;
10 wherein there are separate point-to-point data paths between each one of
11 the directors and the global cache memory; and

12 wherein a pair of the second directors are adapted for coupling to the pair of
13 logic networks.

1 5. A data storage system for transferring data between a host computer/server
2 and a bank of disk drives through a system interface, such system interface comprising:
3 a plurality of first directors coupled to the host computer/server;
4 a plurality of second directors coupled to the bank of disk drives;
5 a cache memory, such cache memory having:
6 a pair of memory boards, each memory board having a
7 memory array;
8 wherein there are separate point-to-point data paths between each one of the
9 directors and the global cache memory; and
10 wherein one of the first directors is adapted for coupling to the memory
11 arrays of the pair of memory boards.

1 6. A data storage system for transferring data between a host computer/server
2 and a bank of disk drives through a system interface, such system interface comprising:
3 a plurality of first directors coupled to the host computer/server;
4 a plurality of second directors coupled to the bank of disk drives;
5 a cache memory, such cache memory having:
6 a common memory array having a pair of redundant data/control
7 ports;
8 a pair of logic networks each one coupled to a corresponding one of
9 the pair of data/control ports;
10 wherein there are separate point-to-point data paths between each one of the
11 directors and the global cache memory; and
12 wherein each one of the pair of logic networks is coupled to one of the first directors and
13 one of the second directors.

1 7. A method for providing a data storage system for transferring data between
2 a host computer/server and a bank of disk drives through a system interface, such system
3 interface having a plurality of first directors, a plurality of second directors, and a global
4 memory, comprising:

5 providing a backplane having slots adapted to have plugged therein a plurality of
6 printed circuit board, such printed circuit boards comprising:
7 a plurality of first director boards having the first directors;
8 a plurality of second printed circuit boards having the second directors ;
9 a plurality of memory printed circuit boards providing the global memory;
10 a plurality of dummy first director boards having first jumpers;
11 a plurality of dummy second director boards having second jumpers;
12 a plurality of dummy memory boards having third jumpers;
13 wiring the backplane to effect a connection among the first, second and
14 third jumpers to interconnect the first plurality of director to the host
15 computer/server, the plurality of second plurality of directors to the bank of disk
16 drives and the global memory to the first plurality of directors and to the second
17 plurality of director; and
18 wherein each one of the memory boards has: a common memory array
19 having a pair of redundant data/control ports; and, a pair of logic networks each one
20 coupled to a corresponding one of the pair of data/control ports; and wherein the
21 printed circuit board is wired to effect a connection with the jumpers to enable a
22 pair of the first directors to be coupled to the pair of logic networks and a pair of
23 the second directors to be coupled to the pair of logic networks.

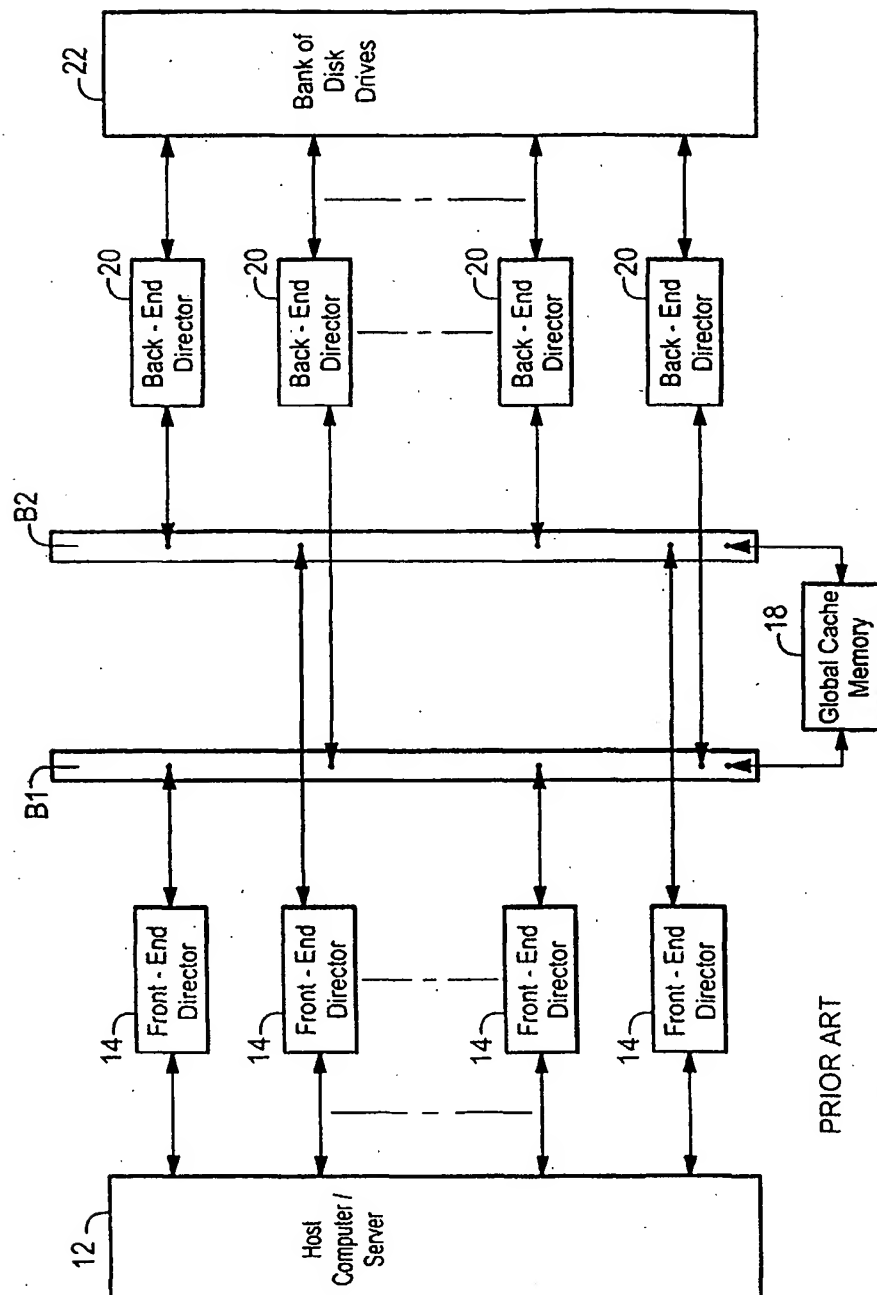
1 8. A data storage system for transferring data between a host computer/server
2 and a bank of disk drives through a system interface, such system interface having a
3 plurality of first directors, a plurality of second directors, and a global memory,
4 comprising:
5 a backplane having slots adapted to have plugged therein a plurality of
6 printed circuit board, such printed circuit boards comprising:
7 a plurality of first director boards having the first directors;
8 a plurality of second printed circuit boards having the second
9 directors;
10 a plurality of memory printed circuit boards providing the global
11 memory;
12 a plurality of dummy first director boards having first jumpers;

13 a plurality of dummy second director boards having second jumpers;
14 a plurality of dummy memory boards having third jumpers;
15 wherein the backplane is wired to effect a connection among the first, second and
16 third jumpers to interconnect the first plurality of director to the host computer/server, the
17 plurality of second plurality of directors to the bank of disk drives and the global memory
18 to the first plurality of directors and to the second plurality of director; and
19 wherein each one of the memory boards has: a common memory
20 array having a pair of redundant data/control ports; and, a pair of logic networks each one
21 coupled to a corresponding one of the pair of data/control ports; and wherein the printed
22 circuit board is wired to effect a connection with the jumpers to enable a pair of the first
23 directors to be coupled to the pair of logic networks and a pair of the second directors to be
24 coupled to the pair of logic networks.

1 9. A method for providing a data storage system for transferring data between
2 a host computer/server and a bank of disk drives through a system interface, such
3 system interface having a plurality of first directors; a plurality of second directors,
4 and a global memory, comprising:
5 providing a backplane having slots adapted to have plugged therein a plurality
6 of printed circuit board, such printed circuit boards comprising:
7 a plurality of first director boards having the first directors;
8 a plurality of second printed circuit boards having the second directors ;
9 a plurality of memory printed circuit boards providing the global
10 memory;
11 a plurality of dummy first director boards having first jumpers;
12 a plurality of dummy second director boards having second jumpers;
13 a plurality of dummy memory boards having third jumpers;
14 wiring the backplane to effect a connection among the first, second and
15 third jumpers to interconnect the first plurality of director to the host
16 computer/server, the plurality of second plurality of directors to the bank of
17 disk drives and the global memory to the first plurality of directors and to the
18 second plurality of director.

1 10. A data storage system for transferring data between a host
2 computer/server and a bank of disk drives through a system interface, such system
3 interface having a plurality of first directors, a plurality of second directors, and a
4 global memory, comprising:
5 a backplane having slots adapted to have plugged therein a plurality of
6 printed circuit board, such printed circuit boards comprising:
7 a plurality of first director boards having the first directors;
8 a plurality of second printed circuit boards having the second
9 directors;
10 a plurality of memory printed circuit boards providing the global
11 memory;
12 a plurality of dummy first director boards having first jumpers;
13 a plurality of dummy second director boards having second jumpers;
14 a plurality of dummy memory boards having third jumpers; and
15 wherein the backplane is wired to effect a connection among the first,
16 second and third jumpers to interconnect the first plurality of director to the host
17 computer/server, the plurality of second plurality of directors to the bank of disk drives and
18 the global memory to the first plurality of directors and to the second plurality of director.

1/13



PRIOR ART

FIG. 1

2/13

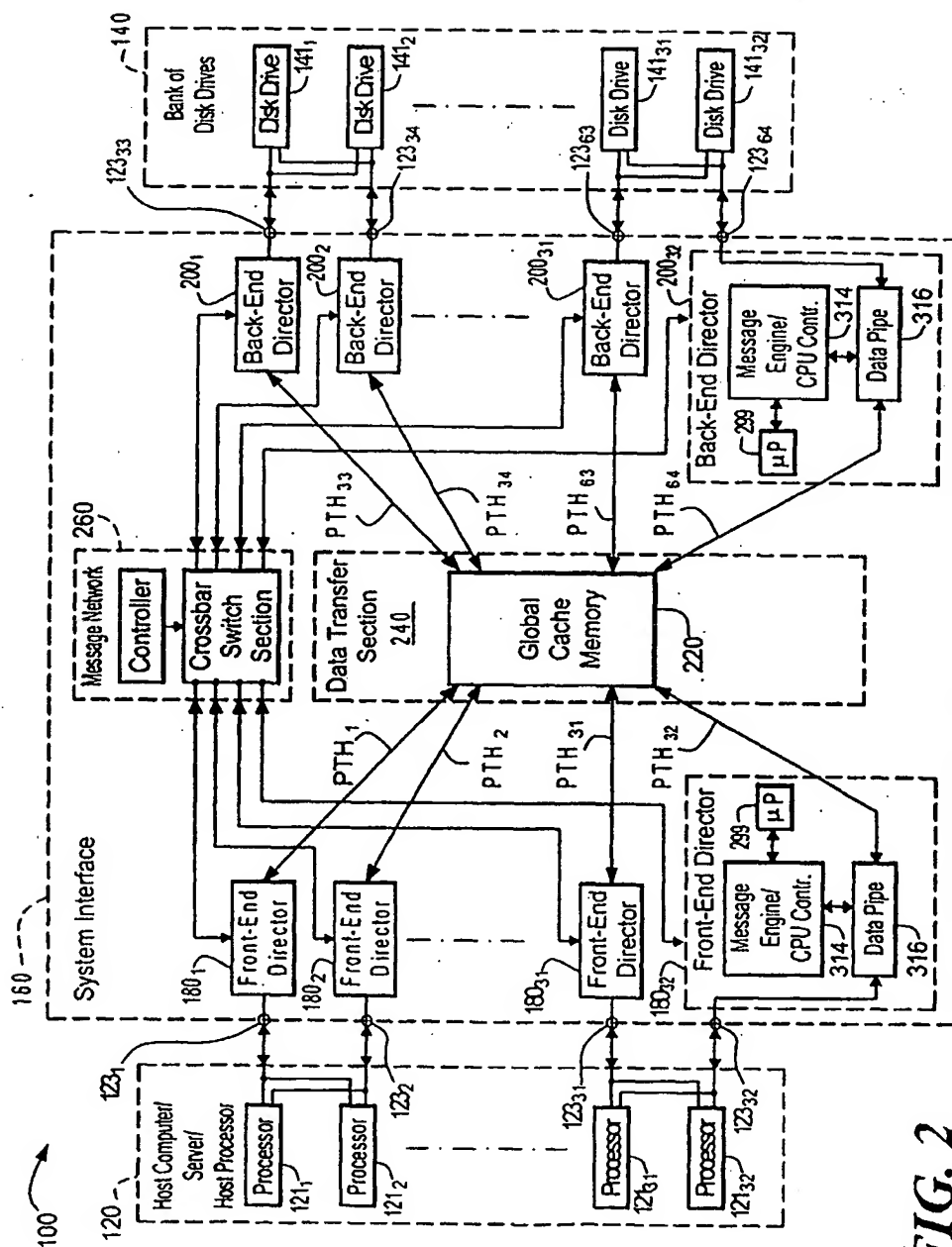


FIG. 2

3/13

FIG. 3

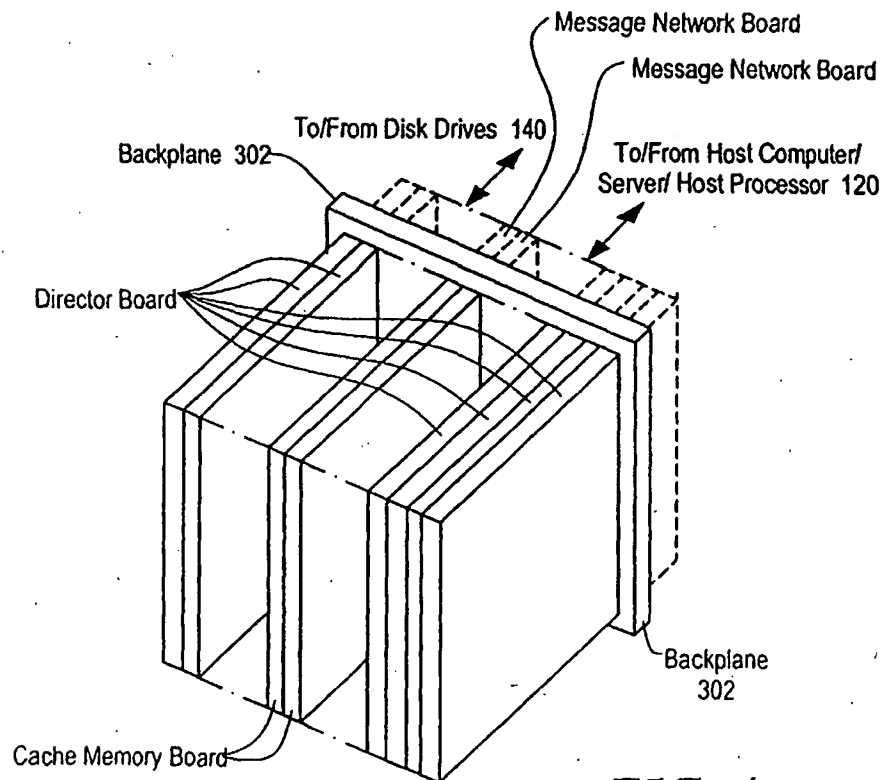
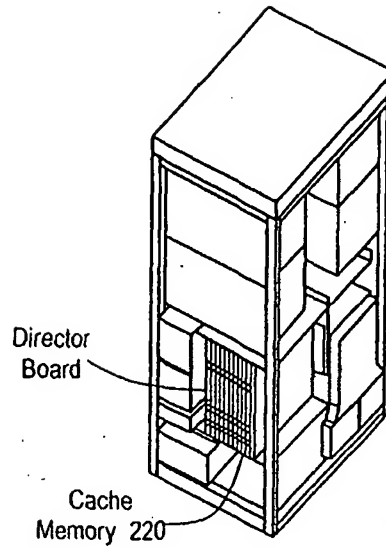


FIG. 4

4/13

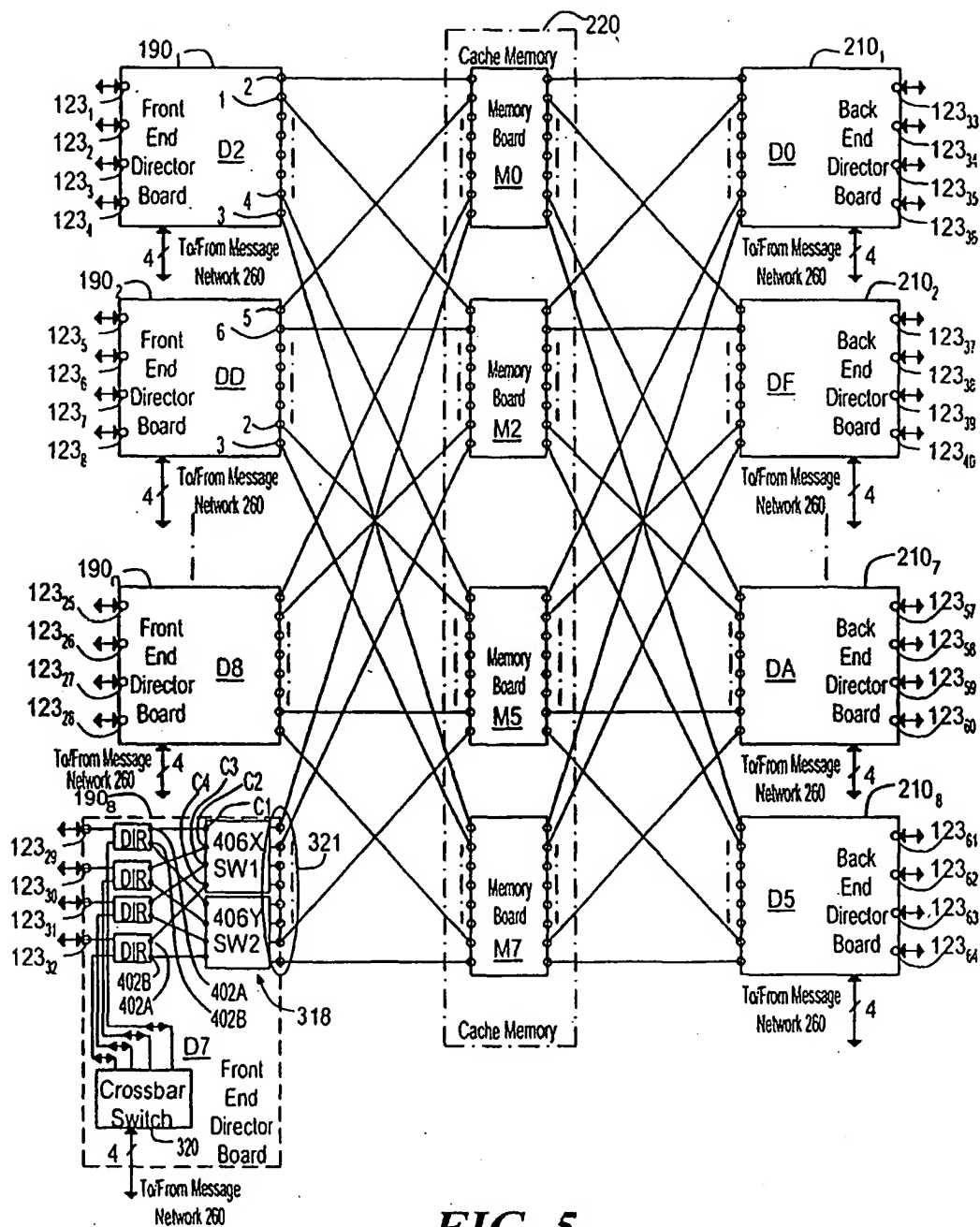
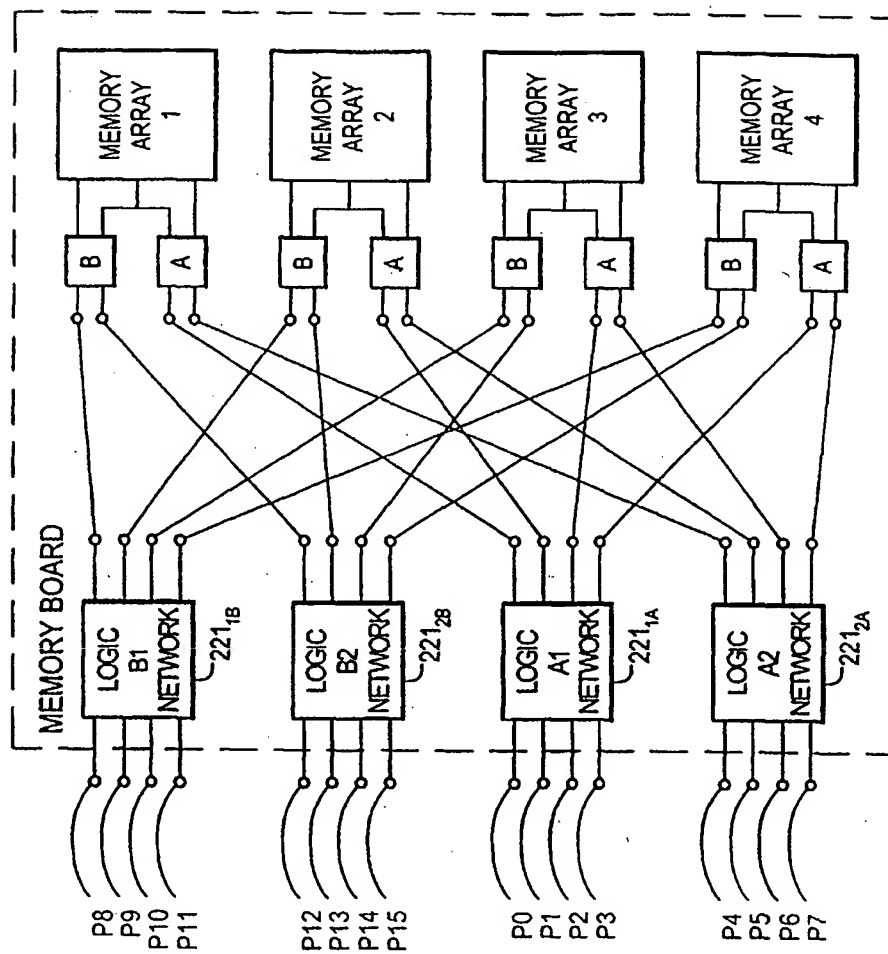


FIG. 5

5/13

**FIG. 6**

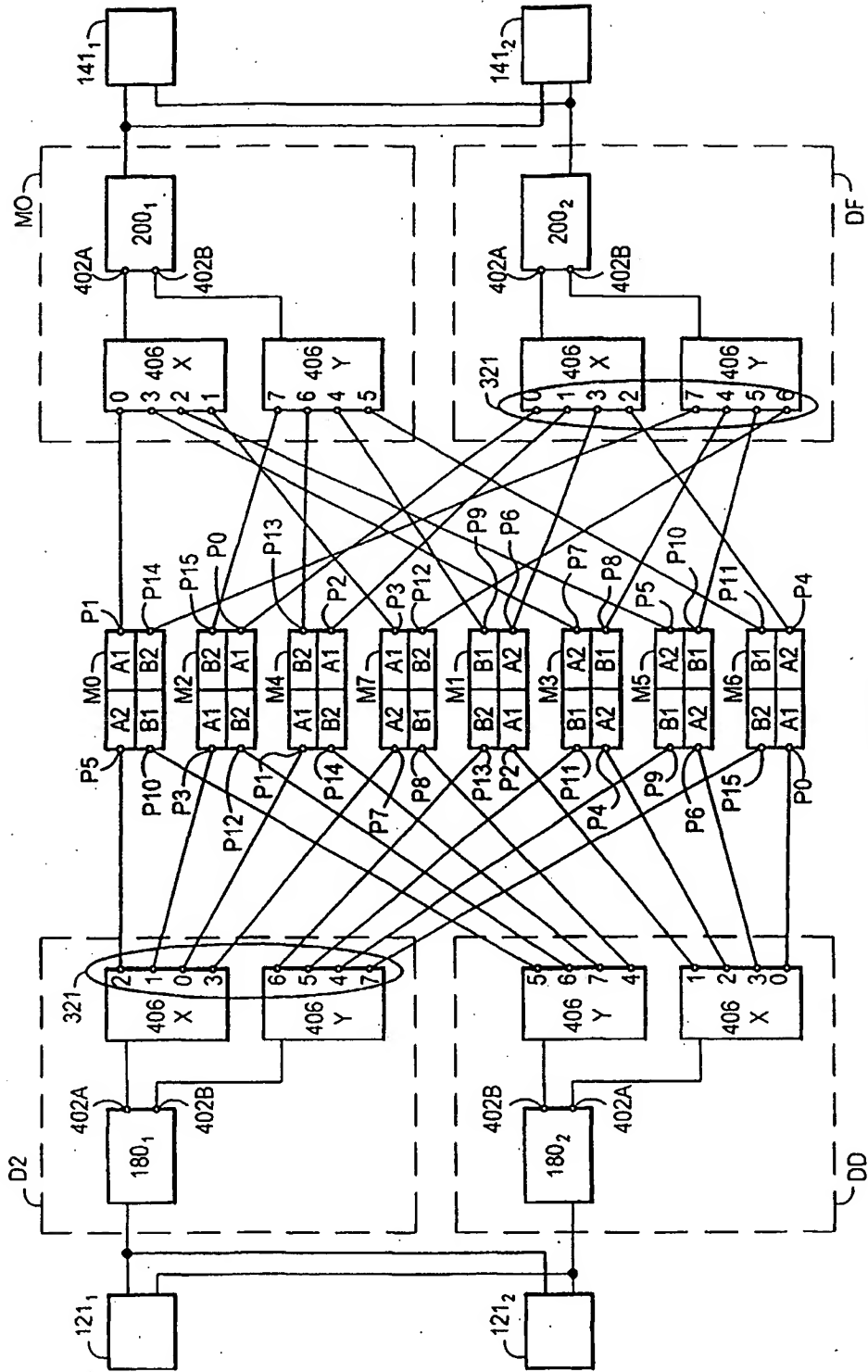


FIG. 7

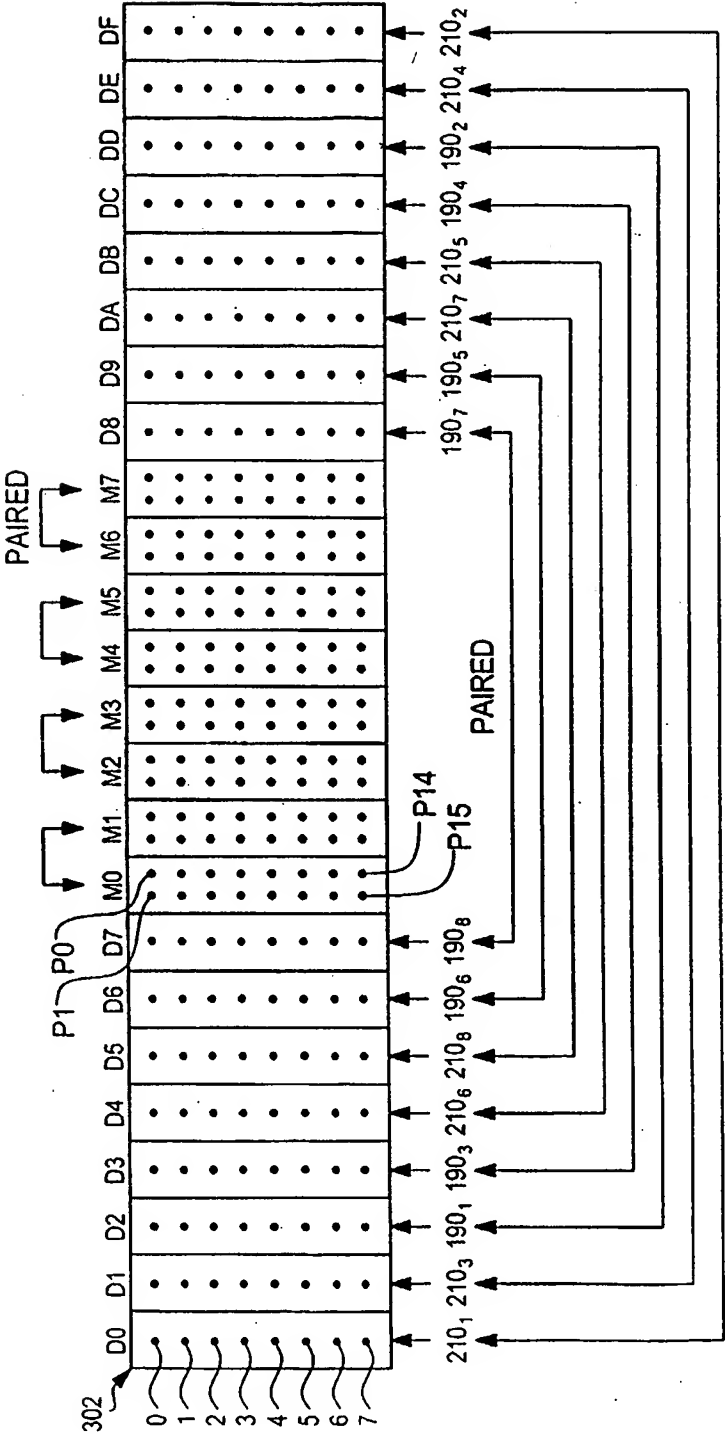


FIG. 8

8/13

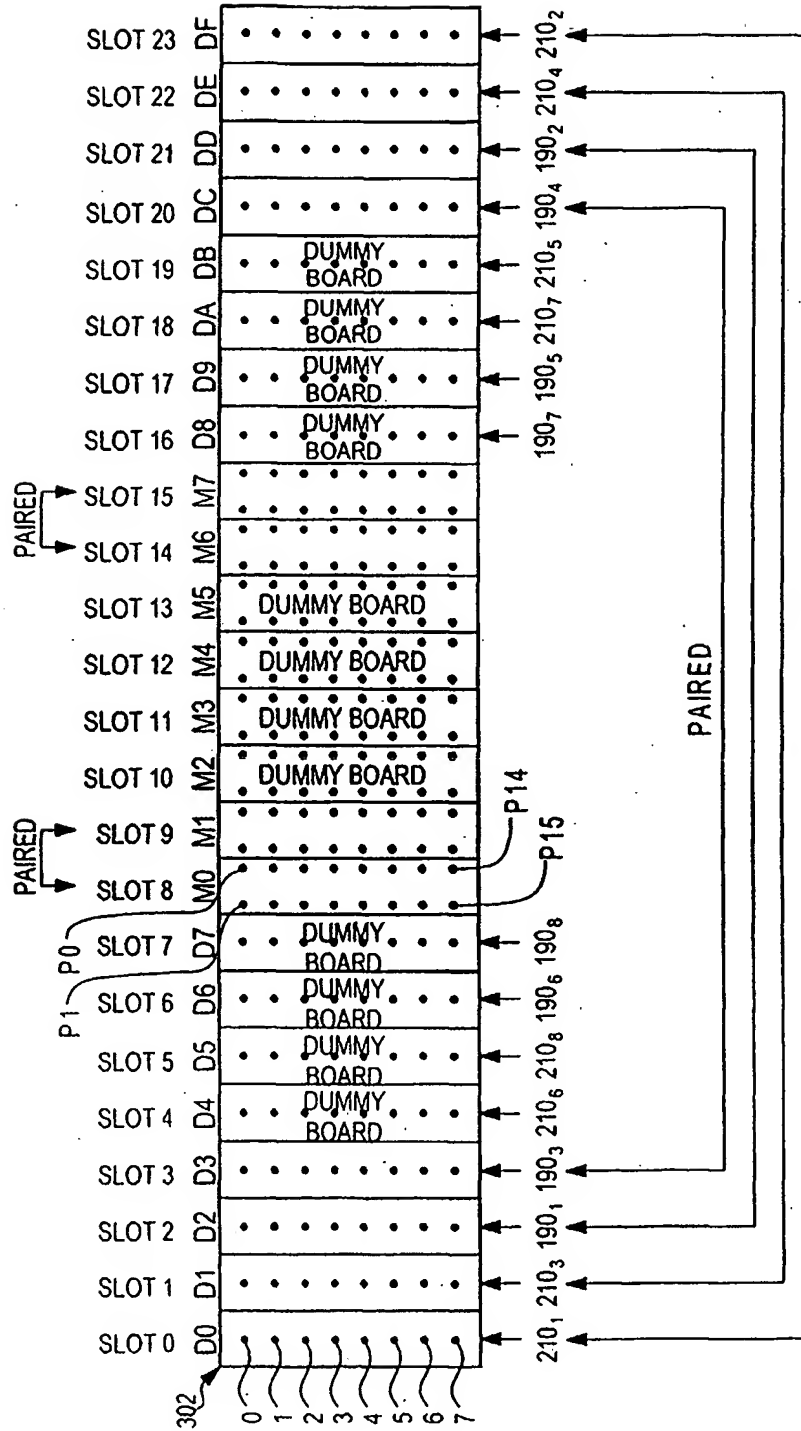


FIG. 9

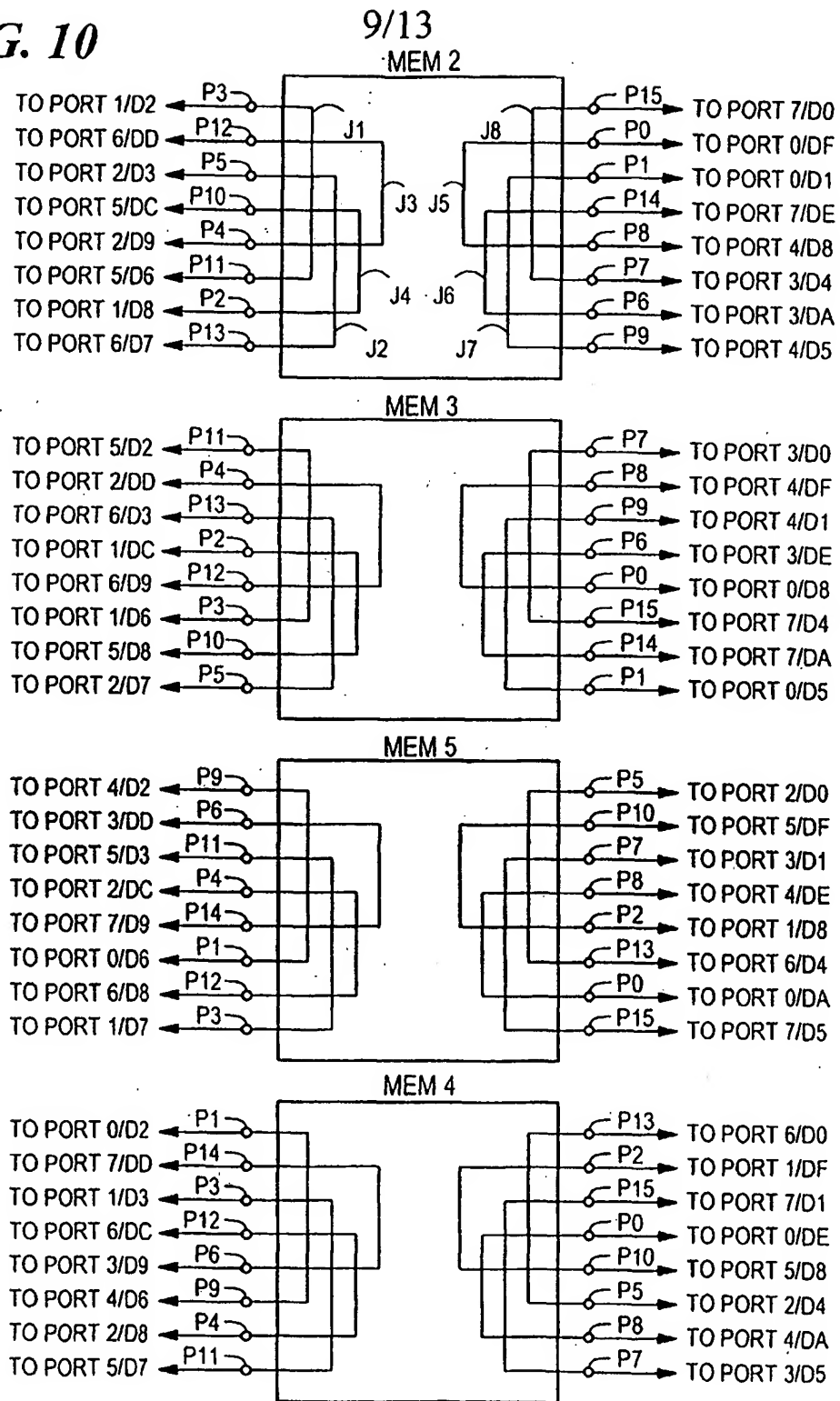
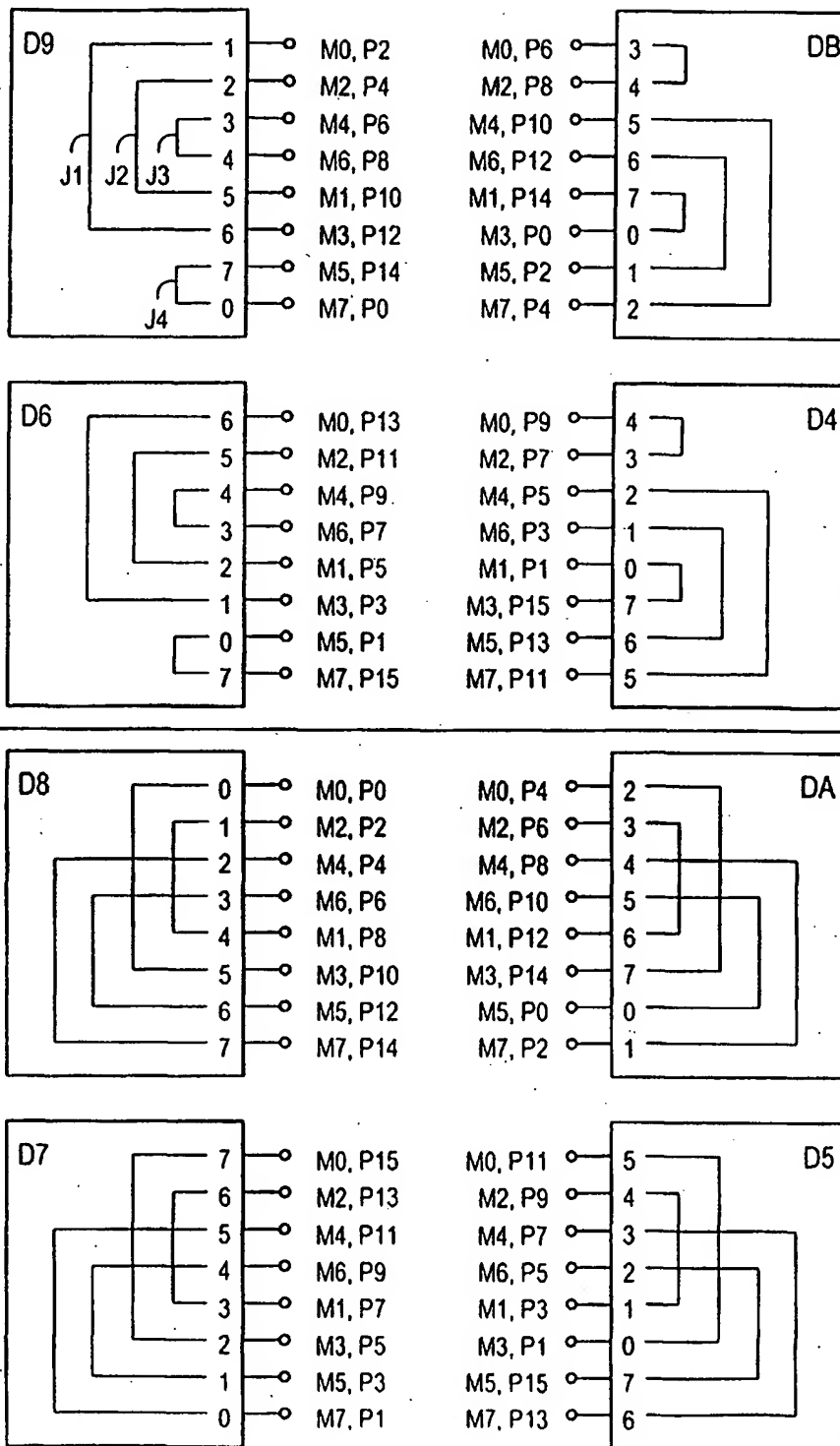
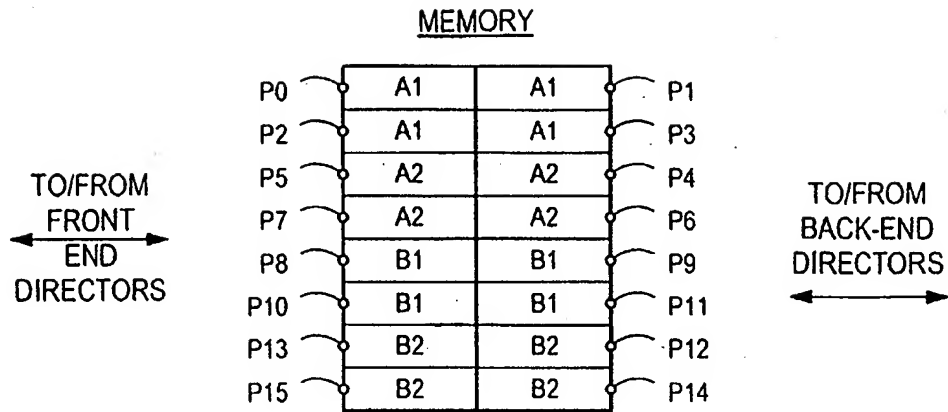
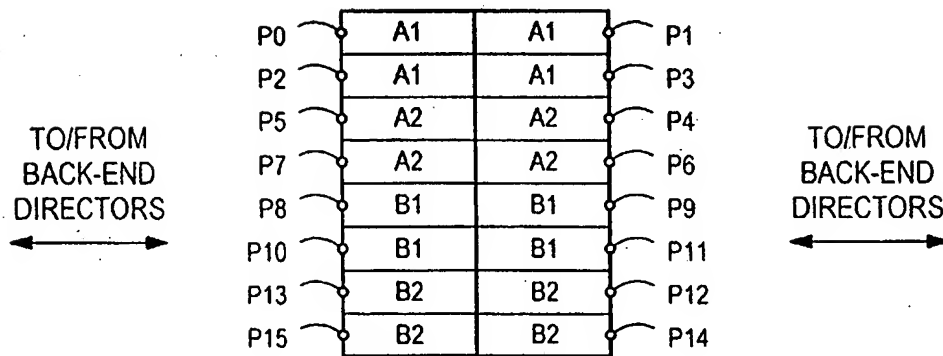
FIG. 10

FIG. 11

10/13



11/13

*FIG. 6A**FIG. 12*

12/13

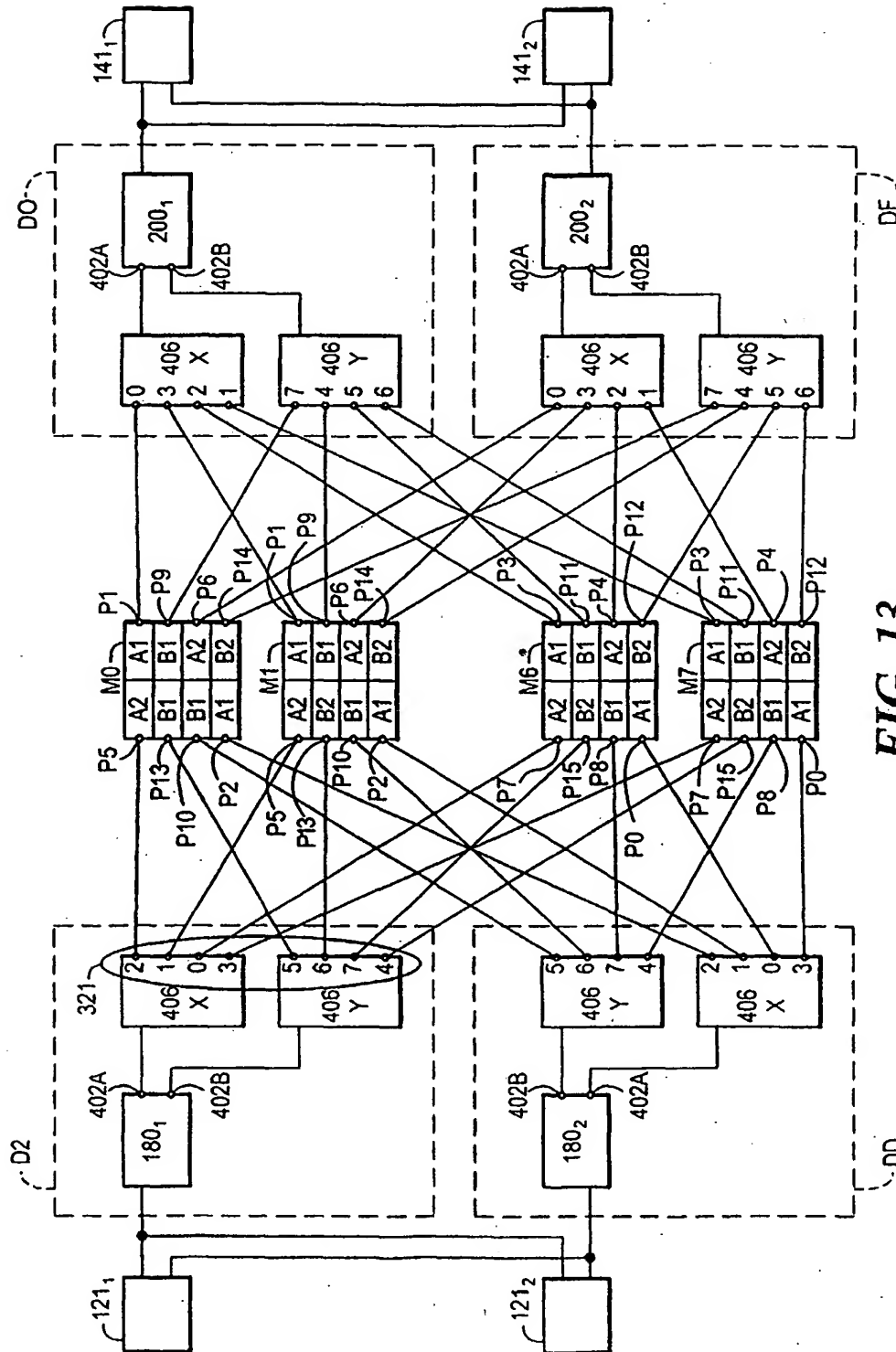


FIG. 13

13/13

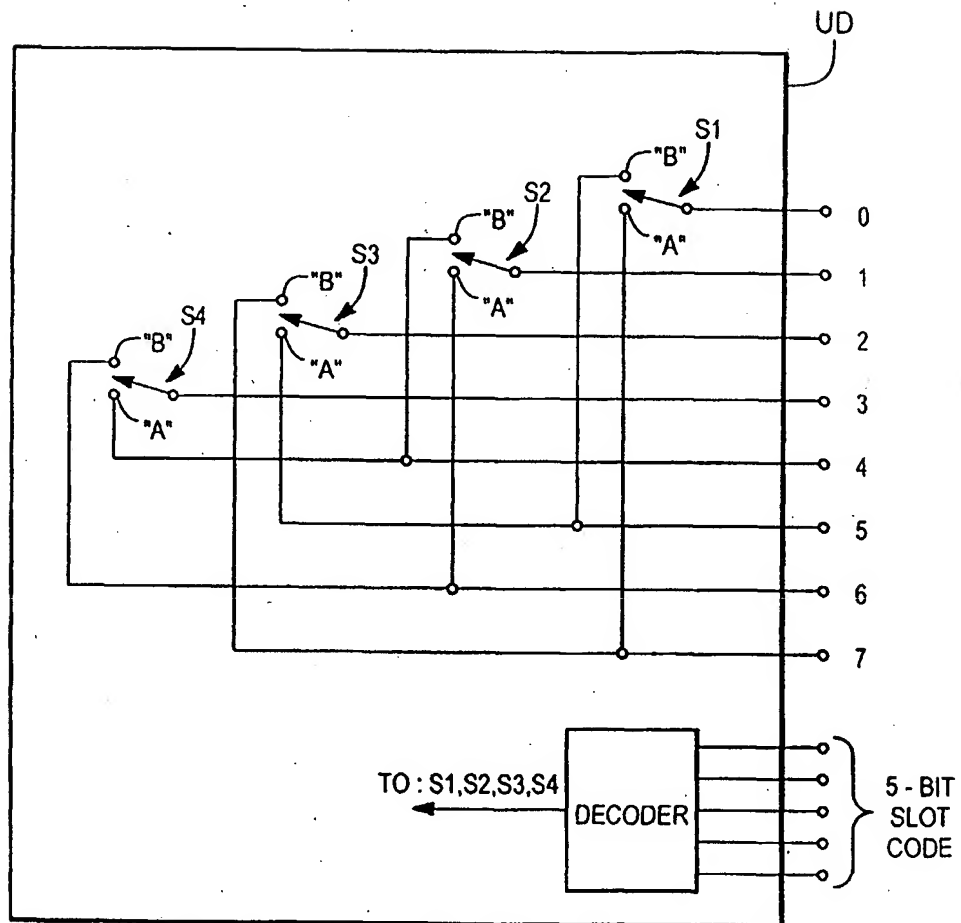


FIG. 14

**This Page is Inserted by IFW Indexing and Scanning
Operations and is not part of the Official Record**

BEST AVAILABLE IMAGES

Defective images within this document are accurate representations of the original documents submitted by the applicant.

Defects in the images include but are not limited to the items checked:

- ☐ BLACK BORDERS
- ☐ IMAGE CUT OFF AT TOP, BOTTOM OR SIDES
- ☒ FADED TEXT OR DRAWING
- ☐ BLURRED OR ILLEGIBLE TEXT OR DRAWING
- ☐ SKEWED/SLANTED IMAGES
- ☐ COLOR OR BLACK AND WHITE PHOTOGRAPHS
- ☐ GRAY SCALE DOCUMENTS
- ☐ LINES OR MARKS ON ORIGINAL DOCUMENT
- ☐ REFERENCE(S) OR EXHIBIT(S) SUBMITTED ARE POOR QUALITY
- ☐ OTHER: _____

IMAGES ARE BEST AVAILABLE COPY.

As rescanning these documents will not correct the image problems checked, please do not report these problems to the IFW Image Problem Mailbox.